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Technical Report

Intra-Theater Auxiliary Lift Ship

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14. ABSTRACT
The objective of this project was to develop a ship concept for Intra-Theater Auxiliary Lift Ship (ITALS), which involves transporting cargo at high speed within a theater of operations. The function of the ITALS vessel is to transfer rolling stock and cargo between cargo ships, Sea Bases and ports. Design requirements for the vessel included sprint speeds of up to 35 knots, a range of 2,500 nautical miles and the use a specified SWATH hullform with good seakeeping qualities and low resistance characteristics at high speeds. ITALS must operate in Sea State 5 and carry a payload of at least 325 tonnes and possess 500 lane-meters of deck space.
A 1,495 tonne concept was designed which provided the required capabilities and had several unique characteristics. The vessel has an aluminum-5086 structure that makes the most of the benefits associated with SWATH hulls. The vessel has a stern vehicle ramp to aid vehicle loading, and a load-compensating crane that can be used to transfer cargo. The vessel uses pumpjet propulsors and uses an integrated full-electric propulsion system. To improve flexibility, significant attempts were made to reduce onboard systems' complexity.

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ABSTRACT

The objective of the CISD Intra-Theatre Auxiliary Logistics Ship project is to develop a concept that addresses the problem of transporting cargo at high speed within an operating theatre. The function of ITALS is to transfer rolling stock and cargo between cargo ships, Sea Bases and ports.

Requirements include using a tested US Navy SWATH hullform with inherently good seakeeping qualities, low resistance characteristics at high speeds, sprint speeds of up to 35 knots and range of 2,500 nautical miles. ITALS can operate in Sea State 5 and carry payloads of up to 325 metric tonnes with 500 lane meters of deck space.

A 1,495 tonne concept was designed which provided a capable vessel with several unique characteristics. The vessel has an aluminum structure that exploits the benefits associated with SWATH hulls. The vessel has a stern vehicle ramp to aid vehicle loading, and a load-compensating crane that can be used to transfer cargo in high sea states.

The vessel uses pump jet propulsors and uses an integrated full-electric propulsion system. To improve flexibility, significant attempts to reduce onboard system complexity were made.

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ACRONYMS

AIM	Advanced Induction Motor
CISD	Center for Innovation in Ship Design
COTS	Commercial Off the Shelf
CR2	Challenger 2 Main Battle Tank
DEC	Directorate of Equipment Capability
DESG	Defense Science and Engineering Group
ECDS	Electronic Control and Distribution Center
ELS	Expeditionary Logistics Support
GT	Gas Turbine
HET	Heavy Equipment Transporter
HSSL	High Speed Sea Lift
IEP	Integrated Electric Propulsion
ITALS	Intra-Theatre Auxiliary Logistics Ship
JHSV	Joint High Speed Vessel
MARS	Maritime Afloat Replenishment and Sustainment
MITL	Maritime Intra-Theatre Lift
MOD	Ministry of Defense UK
MT	Metric Tonnes
NBC	Nuclear, Biological and Chemical
NM	Nautical Miles
PM	Permanent Magnet
RFA	Royal Fleet Auxiliary
RN	Royal Navy
RR	Rolls Royce
SCC	Ships Control Center
SWATH	Small Waterplane Area Twin Hull
UCL	University College London

1 INTRODUCTION

1.1 Mission Statement

The objective of this project is to develop a concept Maritime Intra-Theatre Lift (MITL) vessel to address the problem of transporting cargo at high speed within an operating theatre. The concept (Intra-Theatre Auxiliary Logistics Ship (ITALS)) was developed by CISD but designed mainly with UK MoD standards and will be based on an existing MoD requirement although is not a formal deliverable to the MoD. The role of MITL is to transfer rolling stock and cargo between cargo ships, Sea Bases and austere ports as quickly and effectively as possible under adverse sea conditions.

1.2 Background

MITL is a new concept for global navies, augmenting Joint Logistics Over the Shore (JLOTS) concept with the capability further away from the shore. The objective of a MITL focused design is to enable the high speed movement of priority stores, personnel, vehicles and other assets within an operating theatre. This vessel will be used to transfer vehicles and cargo between vessels within a Sea Base and during seabasing operations.

To do this, the vessel must be capable of interfacing with other ships, austere ports and Sea Bases rapidly and efficiently. Seabasing enables forces to operate ashore without a large logistics footprint and project power onto land while operating in relative safety at sea. To support effective seabasing operations, MITL is a vital, yet underdeveloped capability. Some navies have experience and expertise with MITL operations, but few dedicated vessels have been designed specifically for the purpose. Key characteristics of a MITL design are; good high speed performance, austere access capability, good seakeeping and efficient cargo arrangement.

1.3 Other MITL Style Designs

A number of designs were reviewed in order to gain an appreciation of what capabilities vessels of this class should have.

The main aspect of a MITL capable vessel is its ability to embark and disembark cargo as efficiently as possible. This has been achieved in the concepts below by making use of innovative vehicle loading methods and efficient deck layout. The use of a monohull and a catamaran design for the two concepts shows that a variety of ship types can be used to fulfill the role.

1.3.1 Rolls Royce Intra-Theatre Logistic Vessel[i]

The Intra-Theatre Logistic Vessel is a proposed 2005 design of a steel monohull ‘to deliver capability within operational theatre’. It has a speed of greater than 40 knots.

Accommodation is provided for 32 crew and 350 troops with a cargo area of 2,300 m^2. The length is 121m, a beam of 19m and a draft of 3.15m. It is powered by a RR MT30 gas turbine and uses waterjet propulsion. This design has two vehicle decks accessible by a ramp on a hydraulically operated turntable at the stern. There is also a flight deck for a Lynx helicopter.

Figure 1 - Rolls Royce Intra-Theatre Logistic Vessel

1.3.2 Joint High Speed Vessel (JHSV) 2 Swift[ii]

The JHSV ship is an INCAT built commercial ferry with added military features. It has served operationally as a mine warfare command and support ship and supports modular mission payload initiatives. The JHSV 2 has similar features to those required to fulfill the MITL role. The vessel cruises at 35 knots with a payload of 500 mt, consisting of 350 military personnel and equipment, and is powered by four 7.2MW diesel engines. There are four water jets for propulsion. The vessel is capable of transporting both wheeled and tracked vehicles and helicopters. A stern loading ramp can support a combat ready M1A1 MBT. In addition it is equipped with a load compensating 10 tonne crane.

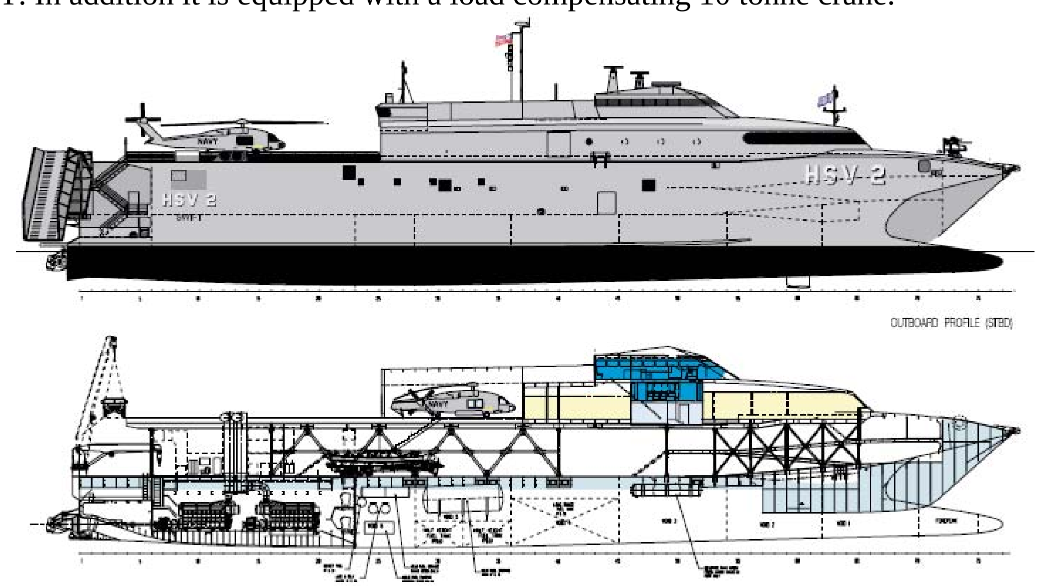


Figure 2 - Incat Joint High Speed Vessel 2 Swift

2 REQUIREMENTS

2.1 Top Level Requirements

The aim of this exercise is to design a vessel to fulfill an Intra-Theatre logistics role. This is predominantly the transport of cargo, both vehicular and palletized. A number of constraints were placed on the design by the operating requirements, which were inspired by the statement at Appendix A.

Requirements	Stretch target	Preferred target	Threshold target
Cruise Speed (kts)	35+	35	30
Sprint Speed (kts)	35+	35+	35
Cargo (mt)	300+	300+	300
Cargo (passengers)	30 passengers with personal equipment for 24 hours	30 passengers with personal equipment for 24 hours	30 passengers with personal equipment for 24 hours
Cargo Area (lane meters)	500+	500+	500
Cargo Area Loading	Withstand loads imposed by any UKMOD vehicle (excluding HET laden with CR2)	Withstand loads imposed by any UKMOD vehicle (excluding HET laden with CR2)	Withstand loads imposed by any UKMOD vehicle (excluding HET laden with CR2)
Range without Cargo (nm)	2,500+	2,500	2,000
Range with Cargo (nm)	1000	500	500
Stores (days)	28+	28+	28
Arrival Draft (m)	< 3 m	< 3 m	< 3.5 m
Cruise Draft (m)	Minimized	Minimized	Minimized
Cargo Transfer (metric tonnes)	5 tonnes of packaged cargo at Sea State 5	5 tonnes of packaged cargo at Sea State 5	5 tonnes of packaged cargo at Sea State 5
Interface (bow, stern)	Interface with Ro-Ro stern ramps at SS4	Interface with Ro-Ro stern ramps at SS3	Interface with Ro-Ro stern ramps at SS2
Interface (port, starboard)	Alongside large shipping at SS5	Alongside large shipping at SS4	Alongside large shipping at SS3
Replenishment	Replenishment by fleet tankers	Replenishment by fleet tankers	Replenishment by fleet tankers

Table 1 - Requirements Specification

The capability of this vessel to beach or dock in water at a depth of two meters was assessed. At the initial design stage, this was considered impractical due to the size of the vessel, its hullform and other technical issues which are associated with docking a vessel. This was not included in the formal requirements list (Appendix B).

The design exceeded some of the requirements in the above table. Cargo weight, cargo lane meters and range reached their hard targets and the range, in some instances reached far beyond the targets. These are explained below:

- **Cargo Weight:** A decision was made to increase the cargo capacity from 300 to 320 mt. This small increase allowed five battle ready Challenger II tanks to be transported as opposed to four.

- **Cargo Area:** The hull which was used was scaled from an existing design which had had model tests undertaken on it. This constrained the dimensions of the ITALS to be scaled as a geosym for the model test data to be useful. As a result the hull proportions are mainly linked to the arrival draft requirements. This in turn defines the length and beam. The resulting area of the cargo deck was larger than the required 500 lane meters. This allows the vehicles to be stored with more space or for more spare room in the cargo deck for light items, although the loading will be limited to 320 mt.

- **Range:** The requirements suggest that a transit mode was possible in which the vessel would carry additional fuel in lieu of cargo. The increased fuel would increase the range and the self-deployment range would be significantly higher. This option was made available for the vessel.

2.2 Standards

Due to the non-combat role of the vessel, it was designed to commercial ship standards with naval standards being applied in cases where it was deemed appropriate.

The naval stability standards in use were the MoD Defence Standard 02-109 Part 2[iii]. Also used were the UK Maritime and Coastguard Agency's version of the IMO International Code of Safety for High Speed Vessels[iv].

For the purposes of the concept, only standards which affected the overall design were considered – these tended to be structural in nature. When the detailed design process commences, all IMO standards will be adhered to and the ship will be designed as a classed vessel.

The standards refer mainly to stability in extreme environments and the stability under various damage scenarios. A comprehensive evaluation of the intact and damage stability of the design was not completed. Bulkhead placement was based on the minimum compartment spacing required by the stability standard.

3 DESIGN

3.1 Design Process

A ship design spiral, as shown in Figure 3 was used. The only additional requirement was the use of a specified hullform. Various methods can be employed to provide breakdowns of each ship subsystem and assign each component within that system a specific weight and volume. In this case, the UCL warship weight and space estimation system was used. The main reason for this was that it is an unclassified system and can be freely distributed. Certain aspects of the weight estimate system, such as the volume or weights of structures would change as it is a twin hull vessel where the UCL system is estimation for a monohull. Where changes have been made an explanation has been provided.

The design process was that of a spiral, where each aspect was iteratively compared with related aspects until a solution was reached. The hullform was already specified and was that of a previously tested SWATH which was a geosym scaled to fit the ITALS requirements and will be described in section 0.

At every design iteration, vertical and transverse centers of gravity were estimated. No longitudinal CoG calculations were made.

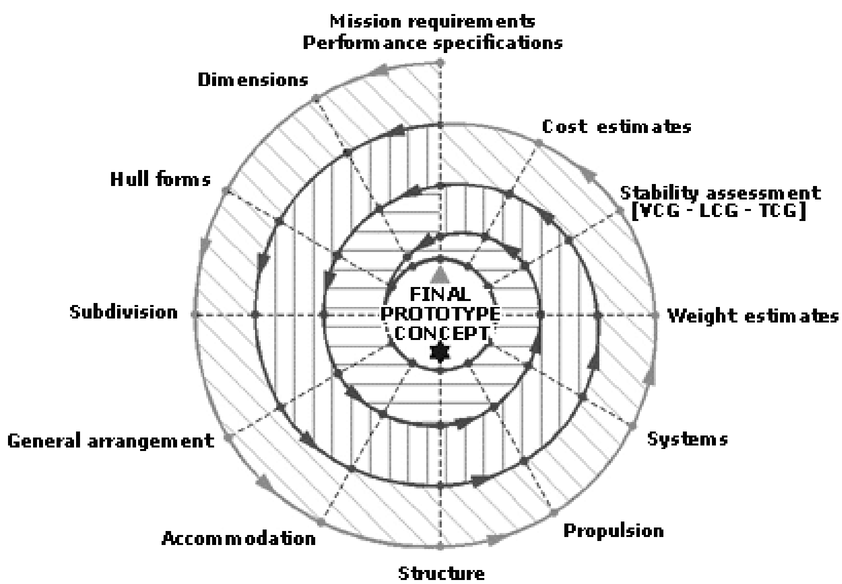


Figure 3 - Ship Design Spiral

3.2 SWATH Hullform

The design requirements specified the use of a specific SWATH design to exploit the availability of model test data. The hullform was from a previously tested design. Appendix H shows the hullform. The hull was scaled in a geometrically similar fashion.

The design of a SWATH is similar to a catamaran, with the hulls more exaggerated. Two buoyant hulls are located below the waterline and are connected to the main decks by narrow struts. The small water plane areas of these struts reduce wave-making resistance which becomes a major factor at higher speeds. This hull provides a high ratio of deck area for its relative displacement, which is a key requirement of MITL.

The SWATH hullform has had hydrodynamic and hydrostatic analyses conducted on it and it is considered to be stable and efficient. Limited model tests were also conducted to measure resistance and motions. The draft of this vessel is relatively low for a SWATH and this was partly why it was chosen for the ITALS concept.

SWATH ships provide significant benefits in seakeeping, operational efficiency and ride quality. Compared with similar sized monohulls and catamarans, SWATHs can operate in higher sea states.

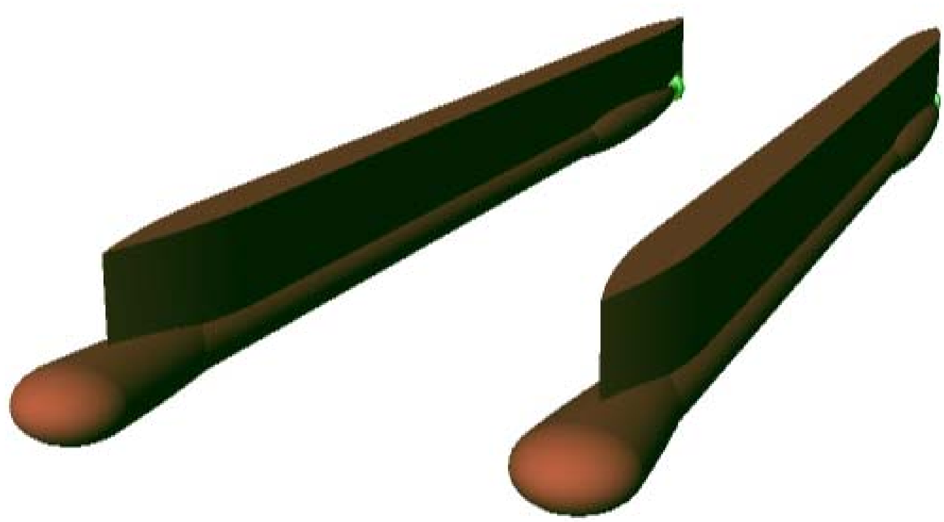


Figure 4 – Tested SWATH Hullform

3.3 General Arrangement

The design of the system went through a number of arrangements before the final system was decided on. The iterative nature of the process meant that each time more detail was put into the database, the weight of the ship changed, therefore the gross size changed as the hullform scaled as a geosym.

Parameter	**Value**
Max Displacement (mt)	1,463
Length (m)	75.9
Beam (m)	20.3
Draft (m)	4.1
Range (Nm)	661 (Max Speed, Cargo Mode) 3837 (18 knots, Transit Mode)
Max Speed (kts)	35
Aircraft	1 Lynx HM. 8
Power Supply	Integrated Full Propulsion 2 Rolls Royce Spey Gas Turbines 2 Cummins DQKH 2.2 MW diesel generators
Propulsion	2 14 MW Permanent Magnetic motors 2 Propulsors
Crew	5 Officer, 11 Enlisted.

Table 2 - Final Ship Characteristics

All cargo is stowed on one deck. The final design included a stern ramp on the cargo deck and a structural sponson system on the bow that allows external ramps to be received from other ships or ports. This means vehicles can embark and alight from either end if another vessel has a ramp to lower onto the ship. At austere ports or landing areas the vehicles can only exit via the stern ramp. The spacing of the vehicles is such that there is a space in the center of the cargo hold for structural supports. There is also space on the port and starboard sides to allow for deck reinforcement. The general arrangement of the design can be seen in Appendix J.

Systems such as the compressed air, chilled water and air conditioning are housed on the main deck but ducting and pipe work are located in the double bottom below the cargo deck.

Located on the weather deck is the helicopter landing area and a 5 tonne static weight load crane. The crane on the weather deck can deposit cargo from (or to) shore from the cargo deck. There is allowance in the weight estimate for a 5 tonne forklift used for moving cargo around. The forklift is stored in the starboard quarter of the cargo hold along with tie downs and other miscellaneous equipment (Figure 8) and is used to move deck cargo to the cargo doors.

There is space for three stairwells on the ship leading from the cargo deck to main deck. Two internal covered stairwells are at the bow of the ship and one is an emergency stairwell at the stern.

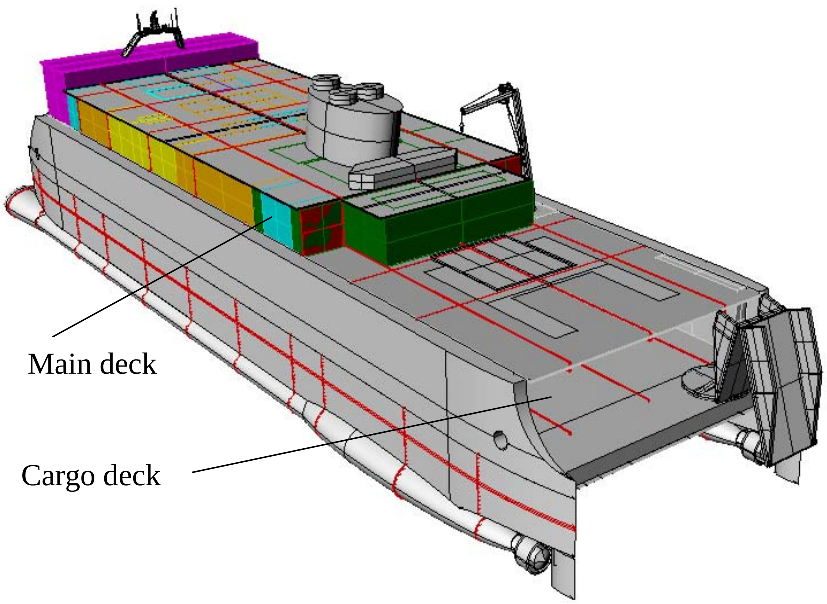


Figure 5 – ITALS Final Design

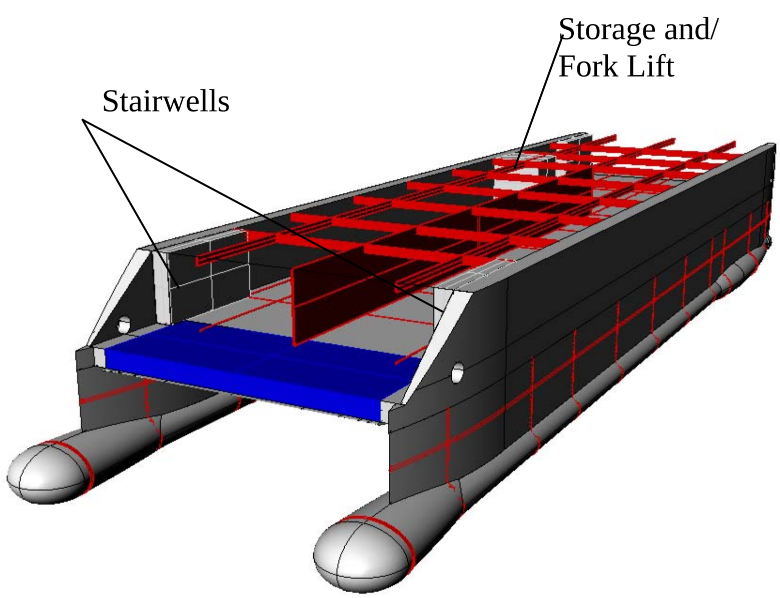


Figure 6 – Internal Bulkhead Layout of Cargo Deck

The main deck layout was designed and shows all spaces that are large enough to be included in a simple general arrangement.

After the compartment locations had been finalized, the bridge was raised half a deck to provide all round visibility to the officer of the watch.

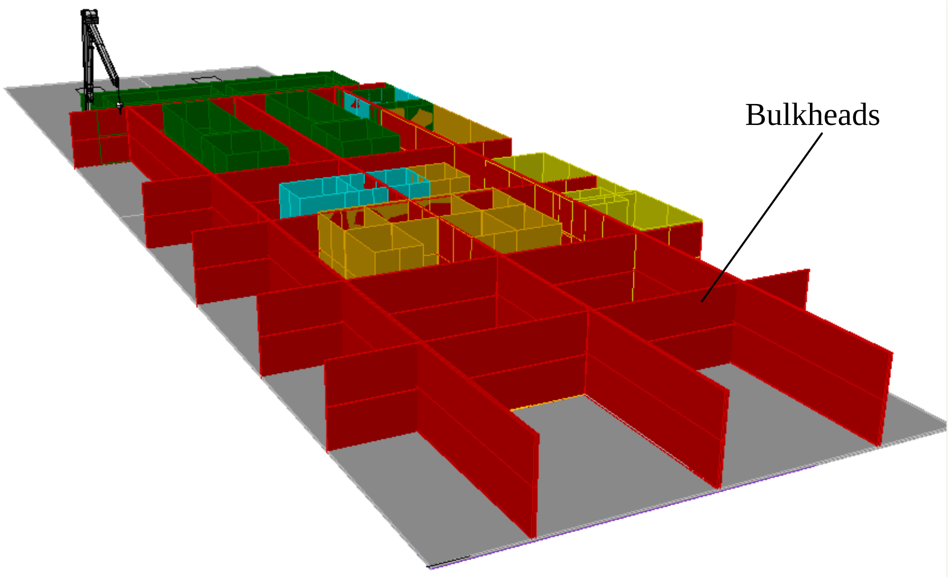


Figure 7 - Main Deck Layout of Compartments

The main accommodation and working areas are situated toward the bow. The engine rooms, electrical and power systems are located amidships. The main accommodation and machinery areas are separated by austere accommodation (which is capable of housing up to 30 people for periods of 24 hours. The full general arrangement can be found in Appendix J.

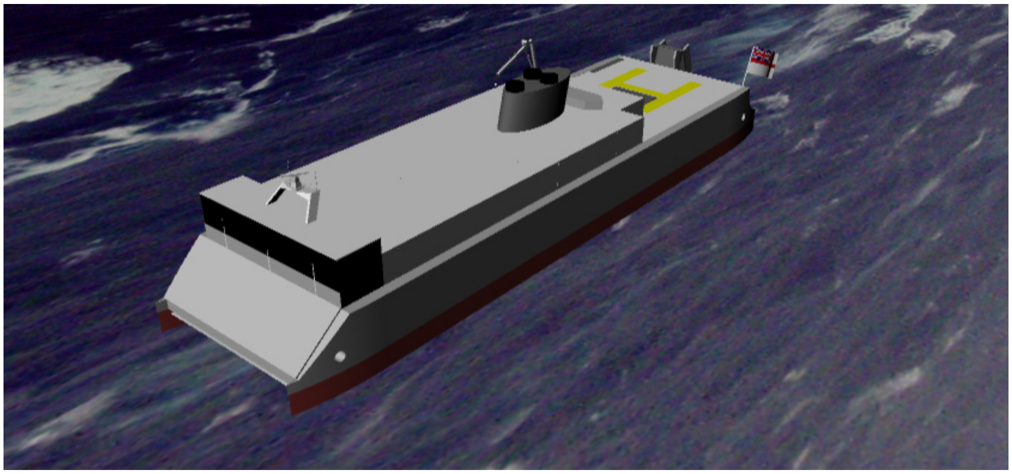


Figure 8 - Final Concept

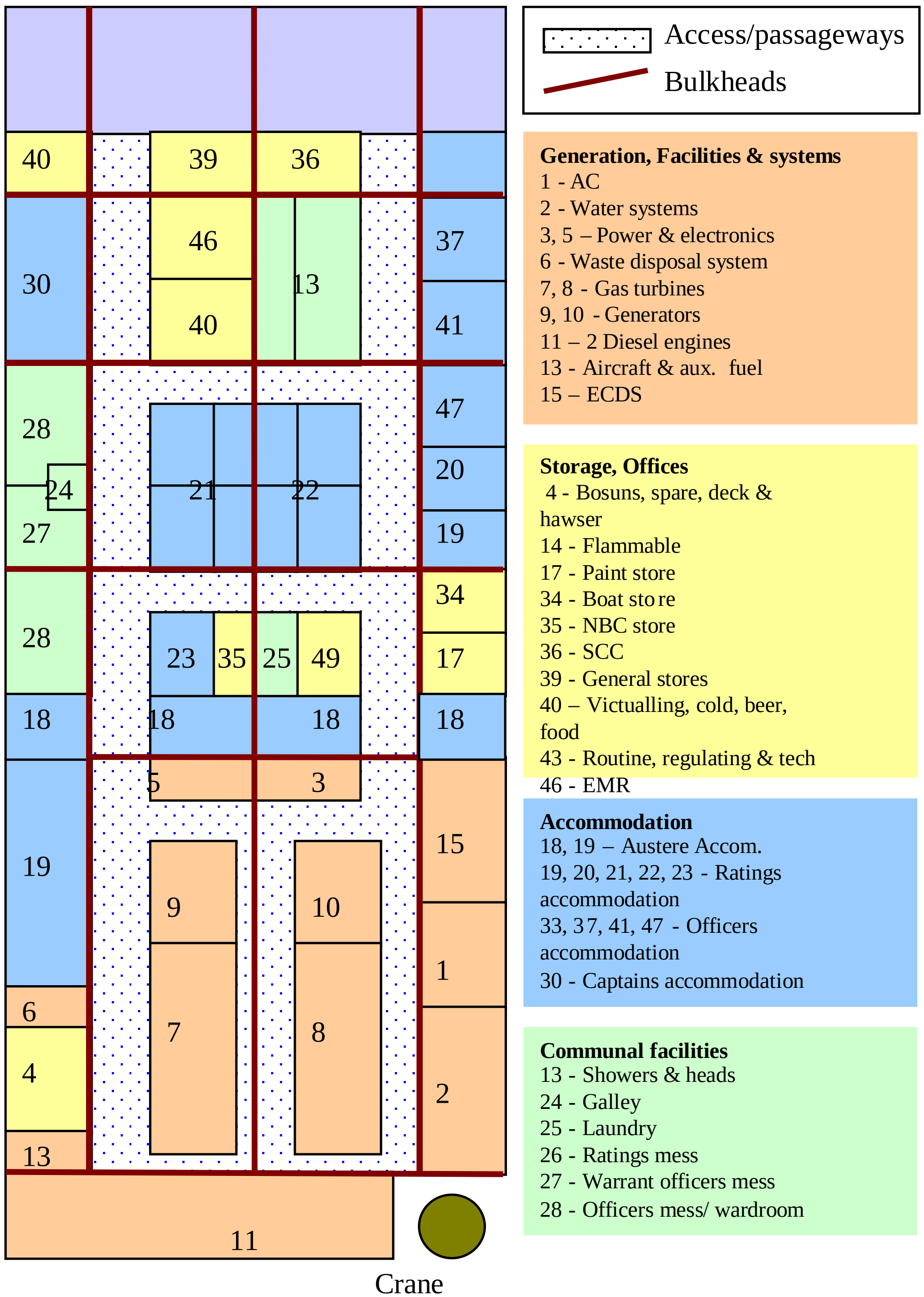


Figure 9 - Main Deck Layout

3.4 Weight and Space Estimates

Weight and space estimates were made following the UCL classification system[v] with adjustments to reflect the MITL mission and the SWATH hullform. In some cases the UCL method was not used, as the ITALS ship is not a warship and the SWATH hullform would most likely be different to those estimates. In all cases a check was made with the scaled weights for the USN X-Craft[vi] to make sure that weight values were similar as this is an aluminum vessel, similar in many respects.

Table 2 below summarizes the estimated weight and volume of the major sections of the ship, all weights include margins detailed in each section. Each of the sections will be discussed individually. The general rule for margins was that for a single item over 100 mt a margin of 15% was added. For items over 20 mt it was 10%. The rest had a 5% margin. Once this was established the list was reviewed and the margin on each was increased or decreased according to how confident the value was.

Table 3 details the maximum weights when loaded for deployment as well as for the MITL mission. The maximum displacement (including the margin) will be 1,519.4 mt.

Weight Group	**Volume (m^3)**	**Weight with Margin (mt)**	**Average Group Margin (%)**
Hull	1,095.3	513.7	12.1
Main Propulsion	90.6	208.9	3.6
Electrical Systems	70.4	92.1	3.4
Ship Systems	351.3	173.8	4.8
Personnel	339.5	20.4	5
Lightship	-	1,009.6	-
Cargo	2,872.4	510.5	
Total	4,819.5	1,519.4	

Table 3 - Summary of Weights and Volumes

3.4.1 Hull

The hull category of the weight and space data is a total of 513.7 metric tonnes. All the data, with the exception of the structures was taken directly from the UCL formulated values.

Structural weight was taken from a plot of structural density of vessels with multiple hulls. The structural density is based on the useful volume ratio – the ratio of volume above the cargo deck to total ship volume. Using data from previous SWATHs, catamarans, aluminum vessels and other multi hulled vessels a density value was estimated from data in Appendix G. The useful volume ratio on this vessel was close to 0.7 and the baseline curve was used as the trend. This gave a structural density of just over 2 lbs per cubic foot or 32 kg per cubic meter.

Structures were the most significant unknowns and were given a 15% margin. On average, the hull group had a 12.1% margin.

Group	Category	Volume (m^3)	Weight with margin (mt)	Margin (%)
10	General	590.8	68.3	5
11	Fittings	0.2	25.8	5
12	Navigation	37.8	13.6	5
13	Anchoring & Mooring	38	25.2	5
14	Offices	35	1.2	2
15	Workshops	0	0	2
16	Structures	0	352	15
17	Stores	47	6	5
18	Misc	56.7	21.6	10
Total		1,095.3	513.7	

Table 4 - Hull Weight and Volume Estimate

Workshop spaces are integrated with offices, as the whole overall area is small and can be amalgamated into a single area.

3.4.2 Propulsion

Group	Category	Volume (m^3)	Weight with margin (mt)	Margin (%)
41	Gas Turbines	24	38.8	2
42	Generator	24	36.7	2
43	Steam Turbines	0	0	0
44	Electric Motors	0	44.9	2
45	Auxiliary	0	22.6	2
46	Gearbox	0	0	0
47	Transmission	42.6	47.7	5
48	Propulsor	0	18.2	10
Total		90.6	208.9	

Table 5 - Propulsion System Weight and Volume Estimate

The propulsion system's weight was taken from specific manufacturer estimates for the design equipment. Where bespoke equipment is required and no data is available, UCL estimates were used. The propulsion concept selected is an IEP system, which allows electricity to be generated by prime movers and then channeled either to the propulsors, to the ships services or to both at the same time. It removes the need for direct mechanical coupling of the engines and the propulsors and provides flexibility for other aspects of ship operation. Two 19.5 MW Rolls Royce Spey gas turbines and two 2.25 MW diesels were chosen as prime movers. Again, there was a comparison with the X-

Craft to make ensure that the estimates were representative of high-speed low weight vessels.

Because much of the equipment is specified COTS, a low margin can be used. Where there is an unknown element, a 5% margin is used. The pump jet weights were estimated from water jet weights so a higher margin was applied.

3.4.3 Electric Power Generation

All electrical power during design point operating conditions is generated by the gas turbines. The ship services consume, at full capacity, just over 2.6 MW including a 20% margin due to lifetime increase in consumption. Two diesel alternators were added for slow speed and emergency operation. Commercial off the shelf Cummins DQKH[vii] diesel alternators weighing 49.5 mt in total were selected.

The electrical distribution system, including switchboards and general distribution was estimated from the UCL weight and space table, as was the lighting system.

Specified equipment has a margin of 2% and unknowns have a 5% margin.

Group	**Category**	**Volume (m^3)**	Weight with margin (mt)	**Margin (%)**
51	Diesel Generator	46.4	49.5	2
52	Switchboards	24	19.5	5
53	General Distribution	0	18.8	5
54	Lighting	0	4.3	2
Total		70.4	92.1	

Table 6 - Electrical Power Generation System Weight Estimate

3.4.4 Ship Systems

Weight for ship's systems was estimated to be 171.2 mt, with an average margin of 4.8%. The air conditioning system was sized to be large enough to provide a controlled atmosphere to the cargo deck so that it could act as short to medium term storage area for climate controlled cargo. This was given a 5% margin as equipment can be specified accurately.

Aircraft systems were minimized as no dedicated hangar or any such permanent holding facilities are present. It was envisaged that the Lynx helicopter would only transfer passengers or cargo and undertake limited refueling activities. Sea and fresh water systems were scaled on the ship's gross volume, as were the auxiliary systems.

Group	Category	Volume (m^3)	Weight with margin (mt)	Margin (%)
31	AC, Ventilation & Chilled Water	296.6	55.4	5
32	Sea and Fresh Water Systems	33.4	77.7	4
33	Fuel Systems	0	20.7	5
34	Auxiliary Systems	0	5.1	2
35	Hydraulic Systems	0	16.3	4
36	Compressed Air Systems	13.3	5.3	5
37	Waste Disposal Systems	4	3.5	2
38	Stabilizers	0	0	2
39	Aircraft Systems	4	2	2
Total		351.3	186.0	

Table 7 - Ship Systems Weight and Volume Estimate

3.4.5 Personnel

Accommodation is based on merchant ship requirements since the vessel would fulfill an auxiliary role rather than a warship role. This requires larger accommodation spaces and different standards. A 5% margin was applied to all categories.

Group	Category	Volume (m^3)	Weight with margin (mt)	Margin (%)
21	Personnel	100.4	13.7	5
22	Personnel Support	0.3	1.4	5
23	Stores	6.8	2.7	5
24	Miscellaneous	0	2.6	5
Total		339.5	20.4	

Table 8 - Personnel Weight and Volume Estimate

3.4.6 Payload and Variable Loads

The only systems classed as payload on this ship were the navigation radar and navigation aids including echo sounder. For a vessel of this size, using the UCL data book, payload came to weigh 0.3 and 0.1 metric tonnes respectively.

The grouping of variable loads was such that the vehicles and equipment the vessel carries are classed as the cargo. Fuel was classed under stowed liquids. There are no magazines where weapons are stored on the ship; however the storage areas could store weapons and sensitive munitions as cargo. Personal weapons would also be stored in the austere accommodation area where there is added storage for 30 passengers for 24 hours.

Stowed liquids were unknown so a 10% margin was given. An 8% margin was given to the cargo to allow for any additional items not anticipated at this stage.

Group	**Category**	**Volume (m^3)**	Weight with margin (mt)	**Margin (%)**
72	Victualling & Medical Stores	0	0.6	2
74	Stowed Liquids	126	157	10
77	Helicopter	0	4.5	2
78	Fork Lift	19.4	8.2	2
79	Cargo	2727	328	0
Total		2872.4	498.3	

Table 9 - Variables Weight Estimate

3.5 Stability Analysis

At this concept design stage, a detailed stability analysis was not undertaken as no inherent stability issues are envisaged with the vessel.

3.5.1 Bulkhead Placement

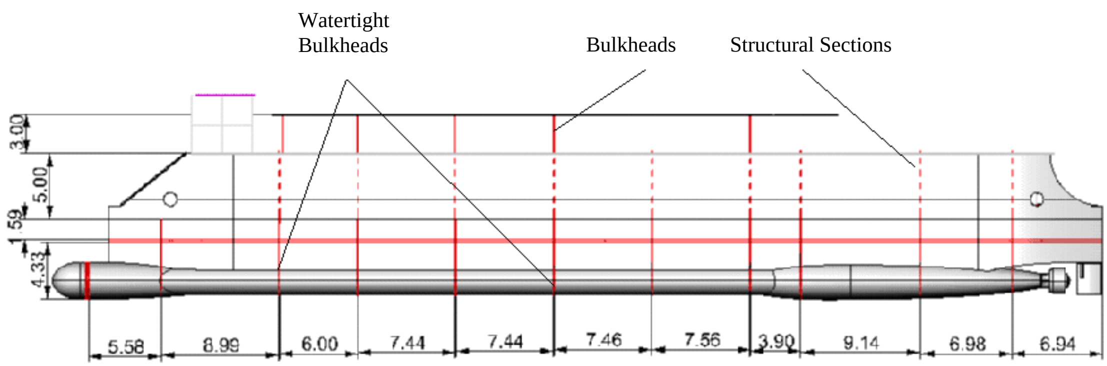


Figure 10 – Transverse Bulkhead Arrangement

The transverse bulkheads of the vessel are arranged as in Figure 10. Each sized to at least the minimum spacing considered allowable. The design intent was for a minimal number of bulkheads to satisfy damage and stability guidelines. According to the guidelines laid out in the HSC 2007, the bulkheads must also be arranged to limit flooding from raking and bottom damage and maintain positive stability.

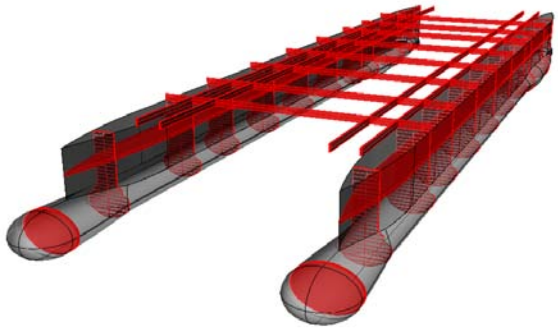


Figure 11 – Bulkheads and Deck in Side Hulls

3.5.2 Survivability Standards

A list of the required survivability standards can be found at Appendix C. The requirements were used as guides to positioning the bulkheads.

3.6 Electrical Loads

The Electrical load requirements were calculated from the UCL weight and space data book according to warship standards. A summary of the values is shown below.

Category	**Load (kW)**
Hull General & Lighting	132.3
Outfit & Furnish	373.8
Systems	1,192.6
Propulsion	243.8
Control	258.2
Total **(With 20% lifetime growth)**	2,200.5 2,640.6

Table 10 - Electrical Power Requirements Estimate

3.7 Propulsion

In addition to the flexible nature of an all-electric ship, an IEP ship lends itself to the SWATH geometry, as power generation machinery can be located in an easily accessible space away from the compact hulls. IEP systems have been fielded on naval vessels and are now a viable option[viii].

3.7.1 Powering Estimates

Since the SWATH hullform used for ITALS is a scaled version of an existing SWATH design, towing test data was used to allow the hull characteristics and effective power requirements to be scaled to the size of the ITALS. The Propulsive Coefficient (PC) was obtained from estimates made by a propulsion expert who determined the PC for 12,000 t and 15,000 t displacement SWATH ships with pump jets. Pump jets designed for these ships were estimated to have a PC of 0.74[ix]. This value was assumed to be constant and was used in the bare hull power calculation where:

(Bare Hull EHP + Appendage losses) x power margin = Fully Appended EHP

Fully Appended EHP / PC = SHP

5% appendage losses and a power margin of 6% were used. Below is a graph that illustrates the relationship between SHP and speed using the data obtained from the towing test.

The shaft power required for 35 knots is 26.3 MW. This value is the total power required at the propeller input, however, the total required output of the engines will be larger due to the efficiencies of the components of the system as shown below in figure 14.

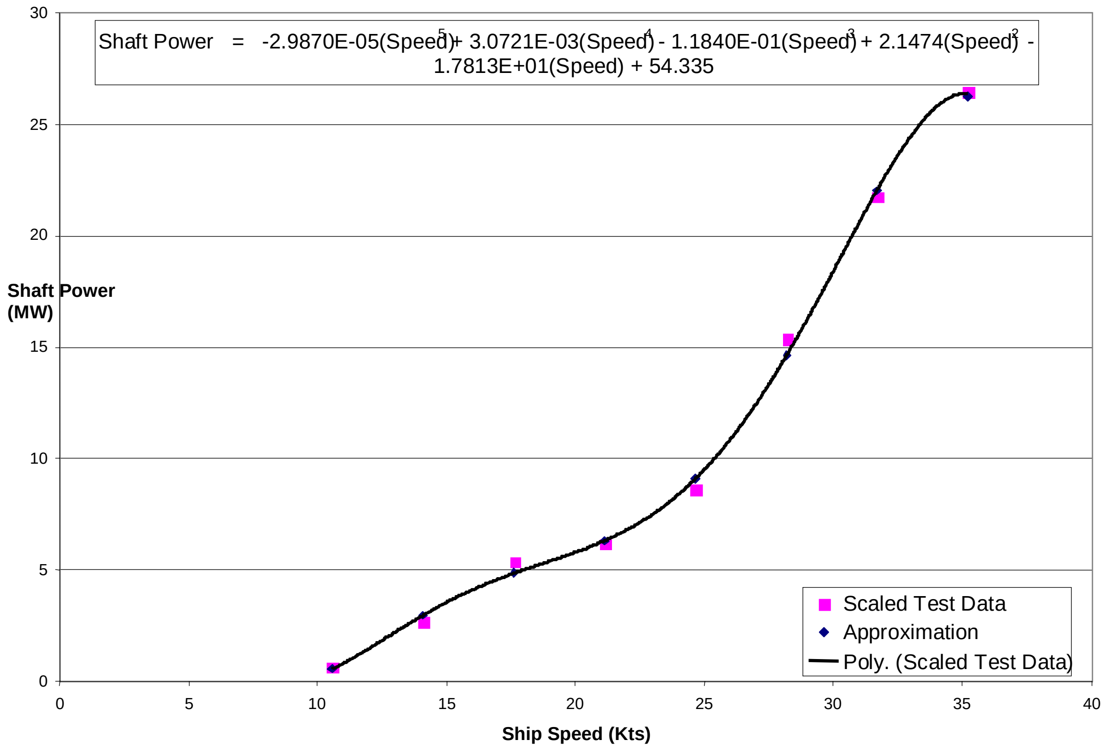


Figure 12 - SWATH Power to Speed Requirements[x]

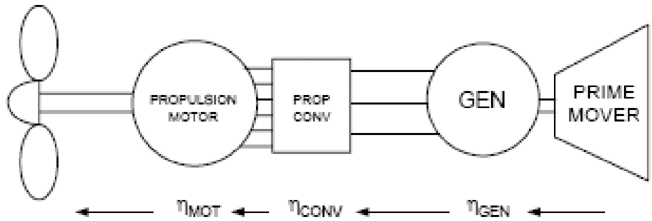


Figure 13 - Propulsion System Efficiency Schematic

$$P_{prop} = \eta_{gen} \cdot \eta_{conv} \cdot \eta_{mot} \cdot \eta_{tr} \cdot P_{pm}$$

Where,

Effective power = P_{prop}
Generator efficiency = η_{gen}
Propulsion converter efficiency = η_{conv}
Motor efficiency = η_{mot}
Transmission efficiency = η_{tr}
Prime mover power output = P_{pm}

Appropriate values for the efficiencies are $\eta_{mot} = 0.96$, $\eta_{conv} = 0.95$, $\eta_{gen} = 0.98$ and $\eta_{tr} = 0.99$

This means that the total power output required by the prime movers for propulsion alone is 29.7 MW that includes the efficiencies mentioned above. To calculate the total power output required from the prime movers, the UCL hotel services power requirement estimates were used, giving a figure of 2.6 MW (with margin and 20% lifetime growth). This produces a combined power output required from the prime movers of 35 MW.

In order to provide sufficient power with the lowest weight penalty, it was decided that gas turbines should be used as they provide a good power to weight ratio compared with diesel engines. Initially, two General Electric LM1600 Gas Turbines were to be used. These generate 28MW between them, which is insufficient when the drive train efficiency is taken into account[xi]. The other potential units that could be used were the GE LM2500 or the Rolls Royce Spey. The LM 2500 generates 22MW, and so would have a large power reserve when the ship was operating at its design point, however, operating the GT at partial power results in poor fuel efficiency and so it was decided that the LM2500 was not suitable. The Rolls Royce Spey is a medium size turbine capable of generating 19.5 MW or 39 MW between two. Clearly, this is in excess of the required power output, and although operating at partial power reduces specific fuel consumption and hence efficiency, the amount this figure reduces is minimal compared with the LM 2500.

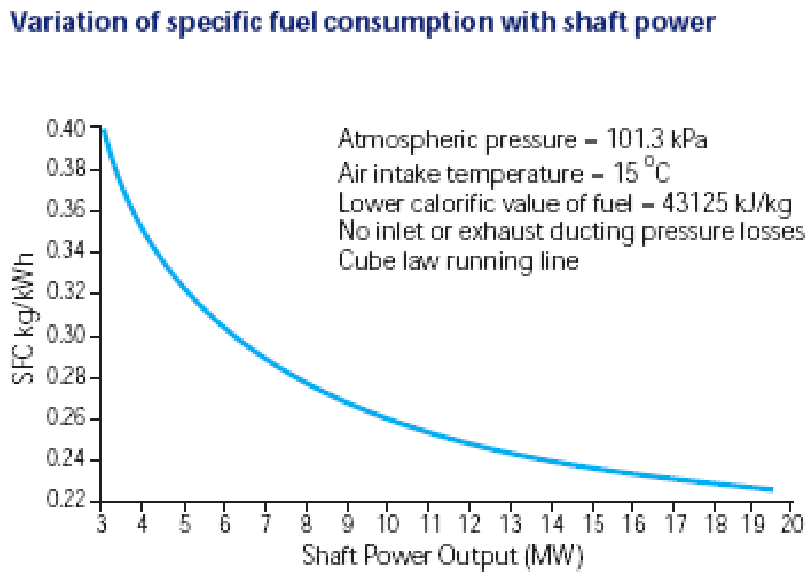


Figure 14 - Graph Showing Variation in Specific Fuel Consumption With Power for RR Spey[xii]

Figure 14 shows that to operate at the required 17.5 MW per engine, the specific fuel consumption (SFC) for each is 0.233 kg/kWhr, which corresponds to a total consumption rate of 8,155 kg/hr. Data obtained from General Electric shows that the SFC for the LM2500 is 0.240 kg/kWhr, which gives a total consumption rate of 8,400 kg/hr. These results show that the total saving in fuel is 345 kg/hr.

Currently, the Spey is in service with RN Type 22 Batch 1 and 2 and Type 23 frigates, which means that there is a significant support network already in place. One issue that needs consideration is the future support of the Spey throughout the in-service life of ITALS.

Each GT will be directly coupled to a 20 MW PM generator, which is a relatively new and developing technology but has become more developed in recent years. There are two types of PM generators, the axial-type and the radial-type. A conceptual study on permanent magnet machinery for ship propulsion concluded that axial generators are impractical but that radial generators are suitable. The axial-type generator is impractical because stresses developed in the rotating portions of the generator exceed the materials capabilities for high-performance rotors at high turbine speeds.

Slow speed and emergency power is to be provided by two Cummins DQKH diesel alternators. The decision was taken to have a supply that would at least be capable of powering the ship's hotel services at zero speed in the area below 3 MW where the Spey cannot generate power. At peak, the hotel load is 2.6 MW so the diesels together must at least have this capacity. It was decided to use two smaller as opposed to only one larger diesel, as this would provide redundancy in the event of a malfunction enabling the ship to move at low speeds. The DQKH is capable of generating 2.2 MW and is known to be a reliable and robust engine.

3.7.2 Converters

From the generators, power will be transferred to a transformer via a switchboard. The transformer will provide both the low voltage (440 VAC 50Hz) for ships services and the medium voltage (4150 VAC) for the propulsion system. To convert the motor supply frequency to a level that is acceptable for the propulsion motors, a variable frequency drive system is required. Factors that need to be considered when selecting the frequency converter include transmission of transient and harmonic distortions. Switching operations are known to cause harmonic effects that can be transmitted through converters in both directions. These distortions can have adverse effects on sensitive equipment on the grid, such as communications and control systems. As a guard against the quality of power supply issues, pulse width modulated link converters are to be used. The converters enable operations that are liable to cause electromagnetic distortions to be completed with reduced chance of effects on more sensitive parts of the system, thus improving the quality of power supply.

3.7.3 Propulsion Motor

The principal alternatives for propulsion motors are Permanent Magnet (PM) motors and Advanced Induction Motors (AIM). To power the pumpjets located in the hulls of the ship, two direct drive 14 MW PM motors were selected. The reason for the selection of a PM system is due to a number of characteristics that are more favorable in this application than AIM. PM motors have high reliability since there is no brush wear, even at high speeds. This is vital, as the motor will be located in the SWATH hull and so is difficult to access for maintenance. The efficiency of PM motors is intrinsically high. Maximum efficiency is desirable so losses throughout the drive train are minimized. PM motors operate with very smooth rotation so no torque ripple occurs during use, allowing the propeller to function more efficiently. High torque can be generated at low speed, which is required so that the motor can be matched to the propeller. The motors will be operated at the same speed as the pumpjet so that reduction gears are not needed and the speed of the motor is controlled by the variable speed drive.

Most crucially, a PM motor is smaller and less bulky than a corresponding AIM. It is this fact that enables the motors to be located in the SWATH hulls (in a restricted space) and as a result is a vital design driver for the whole concept. The use of an AIM, while not making the design unfeasible, may reduce the efficiency of the machinery arrangement and require design changes to be made both to the hull design and to the power and propulsion system.

Figure 15 shows two currently available PM motors that have been used to estimate weight for the ITALS motors. The weight of a motor that can develop 14 MW is approximately 20mt, and this value will be used for calculations. After evaluating the above figure it is important to note that although the motors required for this concept do not exist, their required capability and performance lie within the bounds of developed technology.

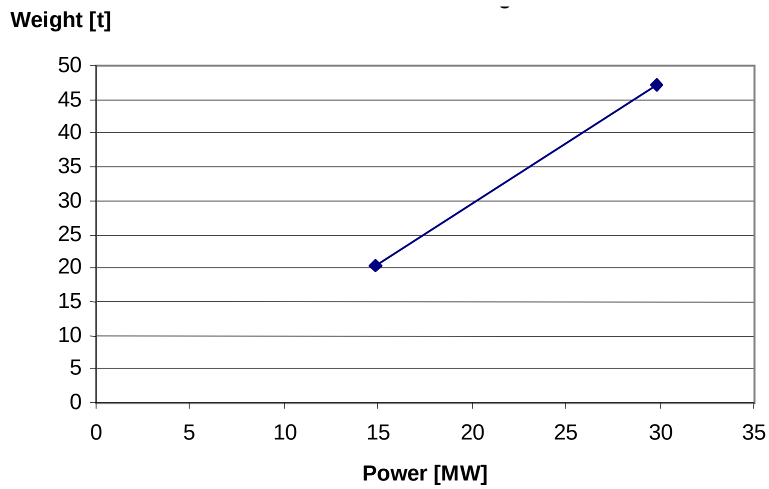


Figure 15 - Power / Weight Characteristics for Existing PM Motors

3.7.4 Propulsor

The propulsors chosen for the design was the pumpjet. A waterjet arrangement was considered but proved less desirable when compared with the pumpjet due to the intake's penetration into the hull and subsequent reduction of hull efficiency. This also adds weight from the body of water flowing through. A pumpjet is essentially a waterjet with an annular inlet and a submerged discharge. Consequently, much of the waterjet technology is directly applicable to pumpjets.

The pumpjet is a fully developed and fielded technology principally used on submarines and torpedoes. There are pumpjets in use today that deliver substantially more power than is required for the ITALS vessel. However, there are no COTS surface ship pumpjets that lie within the necessary power range. Because of this, some development will be needed to design a pumpjet for the concept, and this remains one of the higher risk aspects of the project.

Pumpjets are ideal for use with SWATH forms, since the annular inlets are highly compatible with SWATH stern shapes. Much of the boundary layer, which develops over the hulls during movement, is ingested into the pumpjet. This in turn means that greater momentum can be imparted on the liquid, thus increasing the propulsive efficiency.

To gain an estimate for the weight of each pumpjet unit, a corresponding waterjet was used. The required shaft power was known and this was used in conjunction with Figure

16 to scale the impeller diameter. The data points on the graph were gathered from existing waterjet propulsors and waterjet propelled vessels.

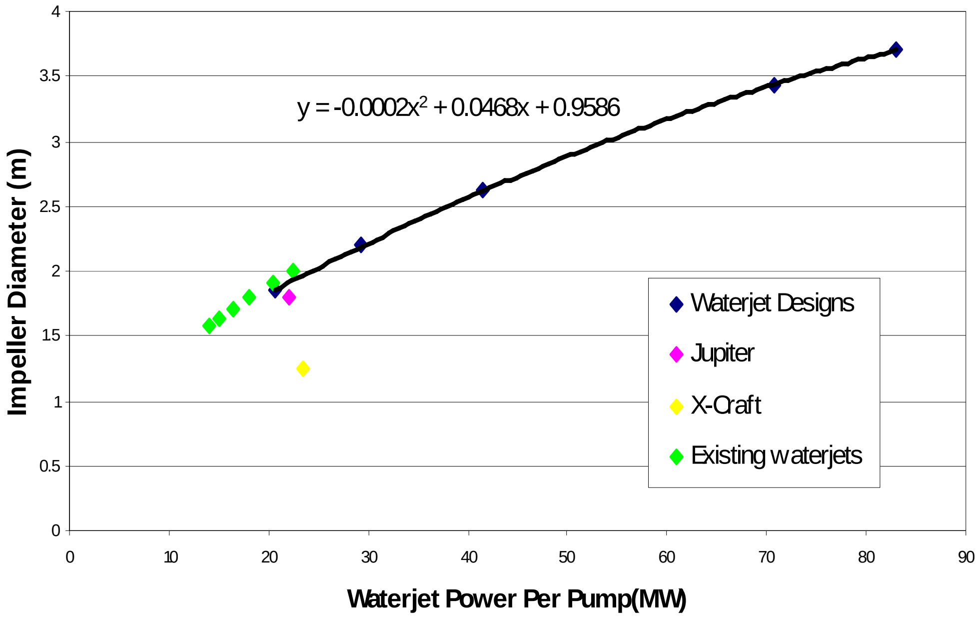


Figure 16 - Waterjet Power Versus Impeller Diameter

In addition to the impeller diameter, similar data was used to estimate the rotational speed of a pumpjet with this impeller diameter at a given power as shown in Figure 17. The estimated pumpjet characteristics are an impeller diameter of 1.6m turning at 500 rpm.

Once the impeller diameter had been established, the weight of the overall unit was estimated using a similar approach. The weight of each unit is 9.1mt giving a combined total of 18.2mt for the entire system.

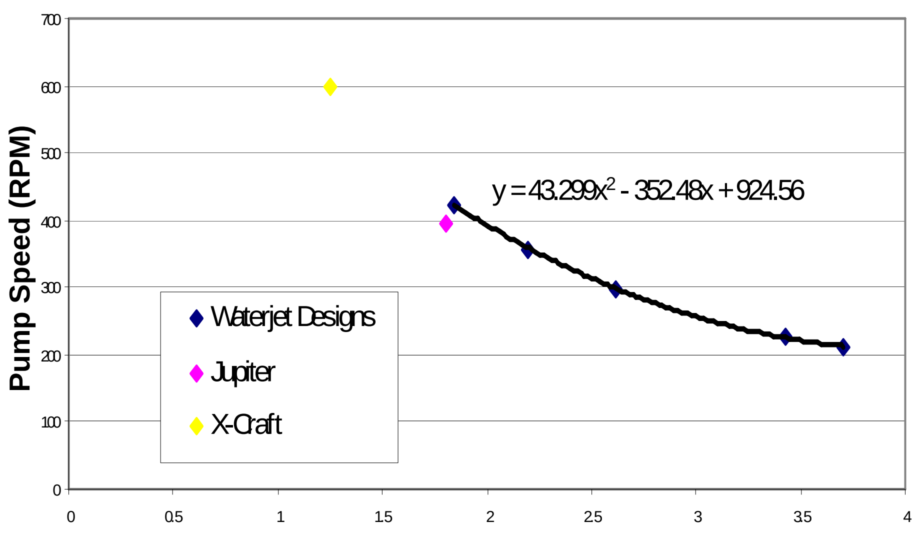


Figure 17 - Impeller Diameter Versus Pump Speed

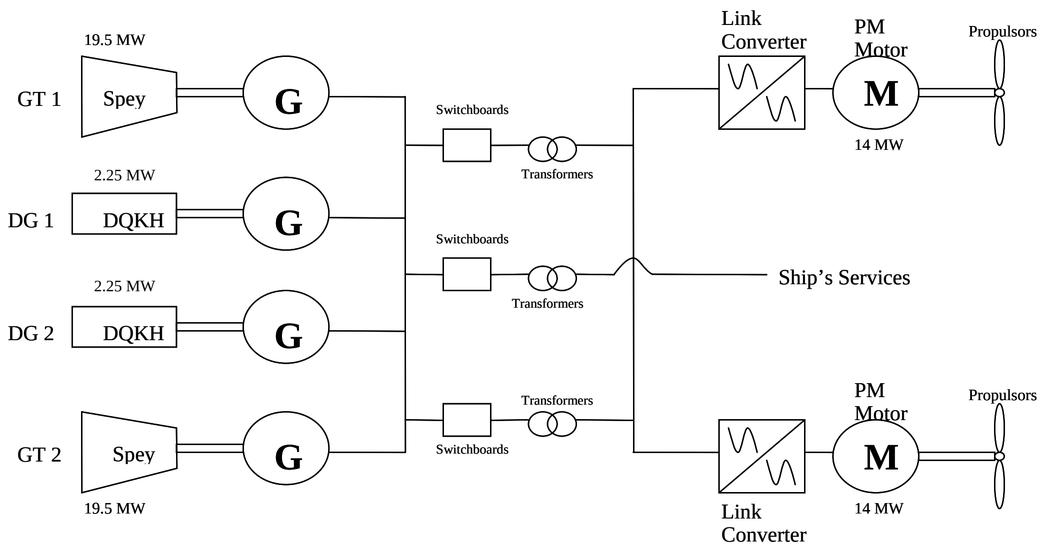


Figure 18 – Propulsion System Schematic

3.7.5 Range

This vessel has considerable range depending on the amount of cargo or fuel carried and the operating regime of the prime. Figure 19 shows the overall behavior of the vessel, in terms of range, throughout its operating speeds. Two fuel endurances are provided in each case, the range with cargo and the transit range with additional fuel supplanting the cargo. All endurances are based on constant displacement and so will be slightly pessimistic as power requirements decrease with displacement. The default setting was the MITL role with 157mt of fuel and 325 mt of cargo plus margin.

The vessel will operate on different prime mover combinations depending on the speed requirement. The low speed operating regime can be accommodated by diesel propulsion alone at speeds of up to 13 knots. This provides a maximum range at of 2404 Nm (with cargo) and 7428 Nm (transit) at 13 knots.

Between 13 and 28 knots one gas turbine and one diesel operate as the most fuel-efficient combination. At a cruising speed of 18 knots the ranges are 1242 Nm (with Cargo) and 3837 (transit). Use of the Gas Turbine by itself without Diesels provides slightly worse fuel consumption but reduces the number of prime movers operating, reducing support costs.

Above 28 knots, both gas turbines are required as this is the only mode that can generate enough power to reach these speeds. At the maximum speed of 35 knots the vessel has a range of approximately 661 Nm (with cargo) and 2043 Nm (transit).

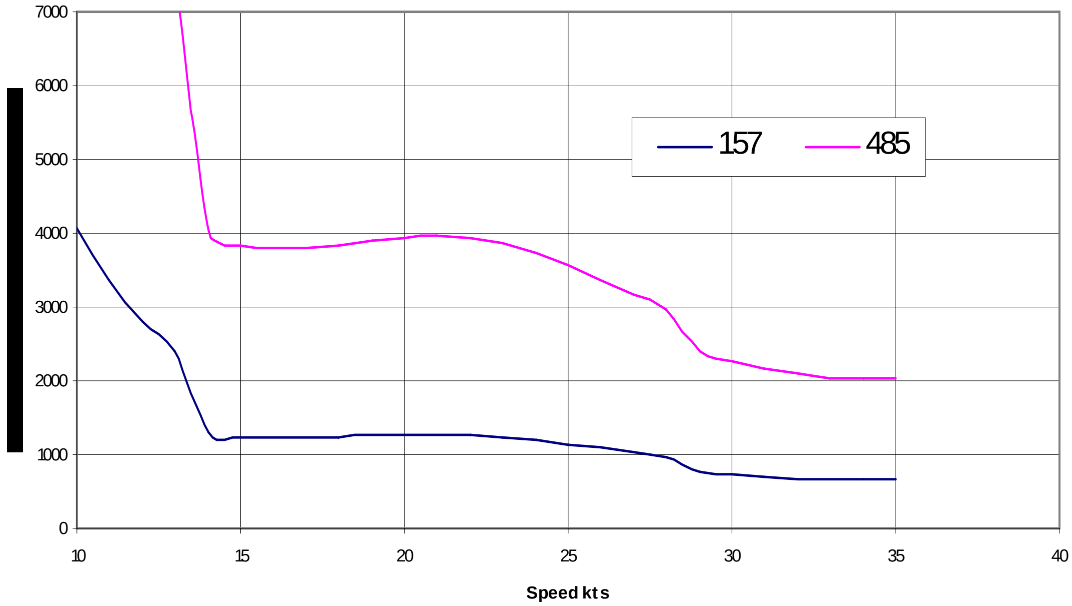


Figure 19 - Optimum Operating Regimes (157 and 485 Tonnes of Fuel)

3.8 Cargo Handling

The two main types of conventional cargo that are accounted for in this concept are vehicles and palletized stores.

Palletized cargo can be loaded onto the ship using a 5 tonne crane. A COTS unit is to be used for this purpose however, cranes with capability to do this at higher sea states are at the prototype design[xiii] stage and if such a design were to mature then they would be used for this application. The crane would load/unload from a Sea Base, other ship or port via loading hatches on the weather deck. Cargo can then be organized with the forklift.

Vehicles are loaded onto the cargo deck from the bow, where the deck itself can support another ship or a port's vehicle ramp. The bow doors open outwards to clear the area for the ramp to be secured. Vehicles drive though the cargo deck and fill lanes accordingly. For unloading, a 15m foldable vehicle ramp at the stern is deployed, and vehicles can disembark by driving straight off. When not in use, the stern ramp can be retracted and folds away clear of the helicopter landing area. The ramp has the same specification as the stern ramp on the JHSV 2 Swift.

The stern weather deck is designed to accommodate a Lynx HM.8 helicopter. Its main uses are movement of cargo and personnel. The maximum weight of the Lynx is 4.4mt, which mandates that the deck itself will require some structural strengthening in order to support the load. This will be achieved by stiffening the deck internally and also by using trussing in the corners where the emergency stairs meet the deck. The hatches are structurally sufficient to take the load of the helicopter although safety clearance would be required.

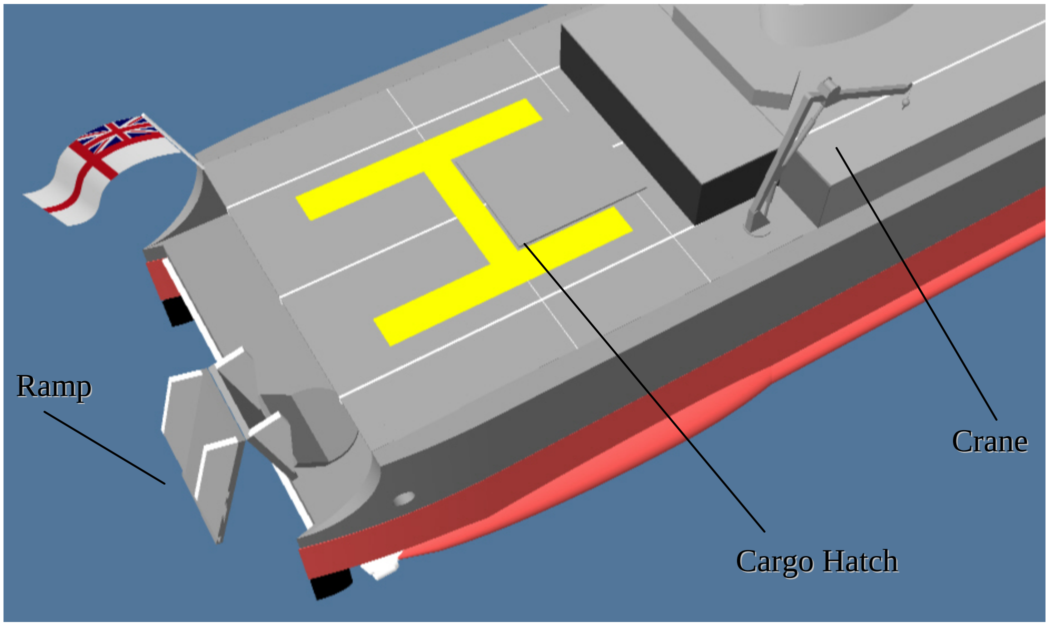


Figure 20 - Stern Cargo Handling Areas

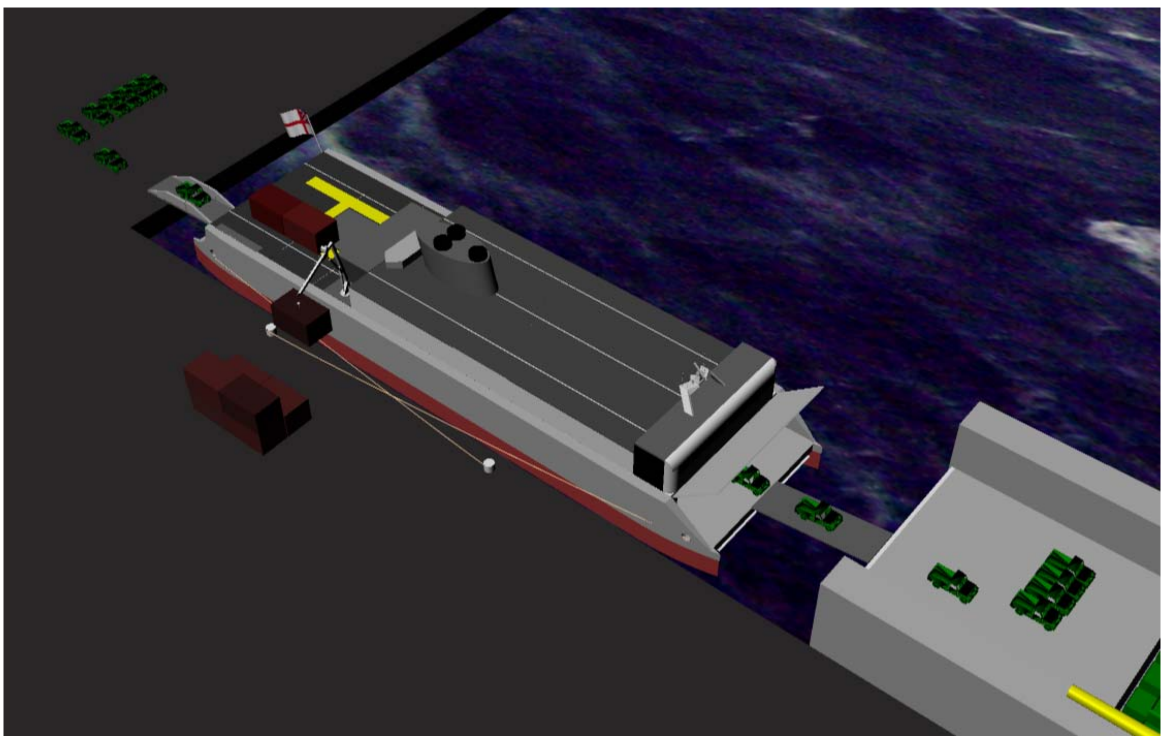


Figure 21 - Cargo Loading

3.9 Risk

As a new concept, a number of risks are inherent in the development of the ITALS. The unconventional design means that there are both technology development and procedural risks involved with the project. Appendix G details the risk matrix.

3.9.1 Compatibility

Integration with Sea Bases or other ships may require some further investigation to ensure that all compatibility issues are identified and addressed. These issues include procedures for transferring cargo at sea, cargo loading plans, and RFA supply etc.

3.9.2 Aluminum Hull

Currently few warships are of aluminum construction and there is little experience in both the manufacture and maintenance of aluminum naval vessels.

Secondly there may be discomfort with using aluminum naval vessels due to the characteristics of aluminum at elevated temperatures. Problems have been experienced with the strength of aluminum under high temperature, however it was considered an acceptable risk to take due as the viability of the design relies on the use of an aluminum hull. The non-combatant role of the ITALS also reduces the likelihood of the ship receiving battle damage that is a likely method of generating the high temperatures required for aluminum combustion.

3.9.3 Permanent Magnet Motor and Generator

PM rotating machinery is a comparatively new technology for marine applications. The applications required for ITALS are outside the boundaries of existing equipment and there is a possibility that the exact machinery specifications may not be deliverable for the concept. In this case alternate systems would have to be chosen, for example AIMs.

3.9.4 Propulsor

Pumpjets have not yet been used for a SWATH application and, while their use is widespread for submarine and torpedo applications, no COTS propulsor exists which could be directly fitted or scaled to the MITL concept.

3.9.5 Cargo Handling Crane

The crane used in this design is a COTS unit, although one that can actively isolate the impact of ship's movement on delivering cargo onto a still surface in a seaway would be preferred. This technology is still in the prototype stages, with work being conducted at Carderock, under USN programs. The promising nature of the work and the number of applications for industry means that the technology will quickly be incorporated into the mainstream.

3.9.6 Gas Turbine not in Mainstream use

The overall use of the Rolls Royce Spey in the future may decline as the only vessels to use it, the UK Type 22 Frigates, will go out of service in the next decade or so. This will have effects on the availability of parts and maintenance.

4 CONCLUSIONS

The objective of this project was to design a vessel capable of fulfilling a MITL role. This concept succeeded in completing the first iteration in the ship design spiral, while meeting the initial design constraints.

The ITALS ship can travel 664 nm when moving at 32 knots laden with cargo, and up to 3837 nm when traveling at 18 knots in a transit condition. Using full-electric propulsion, ITALS vessel will carry 320 mt of cargo between Sea Bases, cargo ships and shore. The concept was designed to reduce through life costs where possible and as a result, is an efficient, and easily maintainable vessel.

A number of high-risk areas have been identified. One of the main risks – the use of an aluminum hull – has been identified, however the risk was deemed necessary for the construction of the ship to be possible. Other risks can be mitigated through research and development.

Although further analysis and design is required, the ITALS requirement has been fulfilled in a feasible manner by this concept design.

5 FURTHER WORK

This project was intended to generate an initial design concept. Therefore the next stage of the process is the detailed design, which can build on the current work. In addition to the detailed design, a number of areas have been identified as requiring further attention:

Stability Calculations
No detailed calculations have been performed to assess the stability of the ship and these must be completed before the design can continue.

Seakeeping Calculations
In order to assess the response of the ship under various sea and loading conditions, seakeeping analysis must be performed, both when the ship is operating alone and during interfaces with other ships at sea. The interface and transfer in seaways must be analyzed not only in terms of the ships stability and motions, but also to verify the capability of the transfer mechanisms under elevated sea states

Risk Analysis – The items in the risk register require further work to determine the risk level to the project and where possible steps should be taken to mitigate that risk.

APPENDICES

Appendix A Original Requirements Email

-----Original Message-----
From: Thorrington, Derrick First Officer Rfa [mailto:Derrick.Thorrington127@mod.uk]
Sent: Wednesday, January 24, 2007 8:10
To: Dicks, Christopher A FORNATL-UK CIV NSWCCD W. Bethesda 2000
Cc: DSTL-Lawrence Alan; DSTL-Broadbent Chris
Subject: RE Request for Ideas

Chris,

Not sure if this is "wacky" enough for you, but I think it may tick some of the other boxes.

Offload of strategic shipping remains a key interest for us here. Assuming that we are in fact talking about lighterage, one of the key aspects of any solution is the ability to get these assets to theatre. For example, RCL is a useful vessel to (slowly) move around relatively large pieces of equipment. However, they have not been used operationally for years because there is no definitive way of deploying them, and spot chartering heavy lift vessels in times of need is both expensive and subject to the vagaries of the market at the time. (RCL cannot self deploy). US capabilities in the form of LCU 2000 have larger lift capability and can self deploy, but at very low speed (not maintaining station within a task group). Furthermore, this speed is seriously affected by sea state.

One of the other areas of concern is that of Maritime Intra-Theatre Lift (MITL) – the movement of high priority stores, personnel, etc within theatre. So far much consideration has been made of rotor craft assets due their ability to interface with both maritime platforms, SPODs and APODs. However, at this stage a maritime platform should not necessarily be ruled out. Speed is of course of the essence. In terms of load, the daily load for ITALS should be assumed to be not greater than 10 tonnes, with individual packages being not greater than 5 tonnes.

The design brief will be for a vessel that can self deploy from the UK to theatres of operation worldwide. It should be capable of speeds of up to 35 knots. The concept will be that the vessel will self deploy to theatre within the task group, acting as the MITL asset on route (although that is technically outside of the MITL definition – but don't worry about that yet). It will deploy in the light condition, therefore able to reach its maximum speed for its ITALS duties. It will be replenished by the fleet tankers on route, but will be expected to be self sufficient for 28 days in all other respects (food only for the regular operating crew).

It is likely that the vessel will be sea state sensitive. To ensure that its ability to self deploy is not compromised, it shall be self sufficient in respects of fuel such that weather routeing may take the vessel around major disturbances and away from the main task group, rejoining as the weather moderates.

When in theatre the vessel will perform both in the MITL role, and as a strategic shipping offload enabler. The stretch target shall be for the vessel to be capable of beaching and offloading wheeled and tracked vehicles directly to the shore. The hard target is for the vessel to operate in water of not more than 2m depth and the threshold target shall be for not more than 3m depth. (It is accepted that the vessel will not be able to operate at speed in shallow waters).

The vessel will be required to interface with typical large RoRo shipping stern ramps for means of transferring vehicles, in up to sea state 4 (stretch target), ss3 hard target and ss2 (threshold). It shall be capable of coming alongside large shipping for the purposes of MITL in up to sea state 5 (stretch), ss4 (hard), ss3 (threshold).

It shall be capable of carrying up to 30 passengers for periods of up to 24 hours. Austere accommodation is acceptable here.

It shall have a total of at least 500 lane metres of cargo space suitable for wheeled and track vehicles.

It shall be capable of carrying a total cargo weight of 300 tonnes

Any ramps / offload devices shall be capable of withstanding the total loads imposed by a CR2 (72 Tonne) and the maximum point loads imposed by wheeled vehicles in the MOD inventory excluding HET in the laden mode.

Hopefully this gives enough information about the design without being too restrictive. It would be interesting to see the study look at the different modes of operation in terms of cargo capacity against speed against fuel capacity. It seems to me that the ability to surge between these three factors may determine the feasibility of such a concept.

Regards,

Derrick Thorrington

Appendix B Modified Requirements - Concept design for ITALS

Requirements
Using information from the Architectural Concepts for High Speed Sealift (HSSL) Phase I report by Bath Iron Works, a concept design to meet a variant of the Intra-Theatre Auxiliary Logistics Ship (ITALS) can be suggested.

The requirements for the ITALS will be as follows:

1. Speed, max 35 knots, cruise 30 knots
2. Deployed light
3. Royal Auxiliary Ships (RAS) replenishment
4. Stores 28 days (only food requirement for the regular crew)
5. Interface with Roll On – Roll Off (Ro-Ro) ferries in conditions of sea state 4 for vehicle transfer
6. Interface with Lift On – Lift Off (Lo-Lo) ferries in conditions of sea state 4 for vehicle transfer
7. Transfer of cargo sea state 5
8. Carry up to 30 passengers for up to 24 hours
9. A total of 500 lane meters of cargo space suitable for wheeled and track vehicles
10. Carry a total cargo weight of 300 mt
11. Any ramps/storage areas to be capable of withstanding total load

An additional aim, which currently is not a solid requirement, is that it should be able to dock at depths of no more than 2m, with a threshold target of no more than 3m.
The aim is to design the ITALS with a tow tank tested USN SWATH form.

The USN SWATH has:

1. Full load displacement 15,850 mt
2. Length 186m
3. Beam 43.7m
4. Design draft 8.4m

Appendix C Survivability Standards

Required survivability	Design
Stability in beam winds Ocean going ship - ability to weather 90 knots	Determined by GZ curve
Stability under icing 150mm of ice on every horizontal surface	An additional 197 metric tonnes are added to the weight of the ship due to this. The ship will sit 0.7m deeper in the water.
Heeling caused by high speed turning Maximum speed at maximum permissible rudder angle	The multi hull design reduces heeling significantly and this can be assumed to be minimal
Lifting of heavy weights 5mt at furthest crane range	Determined by GZ curve
Crowding of passengers	There are a maximum of 46 passengers (including 16 crew) which would be confined to certain areas of the ship and would only cause a maximum of 4 metric tonnes of additional weight.
Water on deck Trapped when substantial bulwarks are present	The nature of the design means that the weather deck is the only surface on which water can collect. The roof above the main deck is purely roofing and is designed to carry water off.
Stability in harbor Heel in a 30 knot wind not to exceed 7 degrees	Determined by GZ curve
Stability during docking	Determined by GZ curve
Stability during firefighting 10 minutes of firefighting and boundary cooling water in large compartments - roll not to exceed 20 degrees	Determined by GZ curve
Any two adjacent main compartments Full flood of compartments	The largest two main compartments are the ones at the bow or stern. This is a 17m hull section. The resultant flooding would only reduce the displacement by 160 cubic meters
Side damage Damage anywhere along its length, extending 15% of the waterline length or 21m (whichever is greater)	To use a more stringent testing, 21m can be flooded. This results in a length of 23m of actual flooding, taking into account bulkhead placing. The volume now displaced is 216 cubic meters extra.
Bottom damage 55% of the length measured from the most forward point of the underwater buoyant volume	Determined by GZ curve

Appendix D UCL Weight and Space Summary

UCL Weight & Space estimate Summary

Table of input values

Variables	Description	Units	Value
He	Area Height	m	4
Vn	Net Volume	m3	6979
Vg	Gross volume	m3	10006
A	Anchors		2
T	Draught		3.8
N	Complement		16
R	Ratings		11
S	Stores endurance	Days	7
Y	Officers		5
L	Length on waterline	m	76
B	Beam		19.76
VH	hull vol		1420
	useful volume ratio		0.697481511
	Displacement Achieved		1462.6

Detailed Tables

				Area	Volume	Tot Vol	Weight	Tot Weight	Margin	Weight estimate
10	**General**	101	Access	0.06		418.74	0.02	40.00	0.05	42.00
		102	Paint			0.00	0.00	22.01	0.05	23.11
		103	Ship control	43.00	172.00	172.00	3.00	3.00	0.05	3.15
		104	WTCs and Voids		0.03	250.15		0.00	0.05	0.00
11	**Fittings**	111	boats			0.00	1.00	1.00	0.05	1.05
		112	Degaussing	0.00	0.00	0.00	0.00	0.00	0.05	0.00
		113	Internal comms	10.00		40.00	5.00	5.00	0.05	5.25
		114	Masts			0.00	5.00	5.00	0.05	5.25
		115	Misc			0.00	0.00	14.00	0.02	14.28
12	**Navigation**	121	Compass platform	21.38		21.38	0.98	0.98	0.05	1.03
		122	Pilotage position			0.00	0.30	0.30	0.05	0.32
		123	Chart room		5.10	5.10	0.60	0.60	0.05	0.63
		124	Gyro compass room		11.20	11.20	7.10	7.10	0.05	7.46
		125	Steering	0.00		0.00	2.70	2.70	0.05	2.84
		126	Misc			0.00	1.30	1.30	0.05	1.37
13	**Anchoring and mooring**	131	Anchors & cables	1.00		4.00	10.00	20.00	0.05	21.00
		132	Cable locker		34.00	34.00	6.10	4.00	0.05	4.20

14	**Offices**	141	Combined routine and ships	35.02		35.02	1.20	1.20	0.02	1.22
		142	Combined regulating and mail	0.00	0.00	0.00	0.00	0.00	0.02	0.00
		143	Combined techinical	0.00	0.00	0.00	0.00	0.00	0.02	0.00
15	**Workshops**	151	Integrated	0.00		0.00	0.00	0.00	0.02	0.00
		152	EMR	0.00		0.00	0.00	0.00	0.02	0.00
16	**Structures**	161	structures	0.00	0.00	0.00	500.30	320.00	0.10	352.00
17	**Stores**	171	Awning	-		0.00		0.00	0.02	0.00
		172	Bosuns	4.30	17.20	17.20	1.00	1.00	0.02	1.02
		173	Confidential book office	1.00	4.00	4.00	0.27	0.27	0.02	0.28
		174	deck	8.50		8.50	0.26	0.26	0.02	0.27
		175	diving gear	0.00	0.00	0.00	0.00	0.00	0.02	0.00
		176	hawser reel	5.40		5.40	2.91	2.91	0.02	2.97
		177	inflammable	4.70		4.70	0.31	0.31	0.02	0.32
		178	naval	0.00	0.00	0.00	0.00	0.00	0.02	0.00
		179	NBCD	7.20		7.20	1.14	1.14	0.02	1.16
18	**Misc**	180	paint	6.70		6.70	0.48	0.48	0.05	0.50
		181	spare gear	0.00		0.01	0.00	0.00	0.05	0.00
		182	boat store	2.80			0.60	9.60	0.05	10.08
		191	Free flooding liquids		50.00	50.00	50.00	10.00	0.10	11.00
						1095.32			**474.17**	**513.75**

				area	**vol**	**total vol**	**weight**	**total weight**	**Margin**	**Weight estimate**
21	**Personnel**	201	Captain		63.10	63.10	2.60	2.60	0.05	2.73
		202	Officers		20.85	83.40	1.65	6.60	0.05	6.93
		203	CPO's		16.40	180.40	0.35	3.85	0.05	4.04
		204	PO's		0.00	0.00	0.00	0.00	0.05	0.00
		205	Junior ratings		0.00	0.00	0.00	0.00	0.05	0.00
22	**Personnel Support**	211	Canteen		0.04	0.59	0.00	0.06	0.05	0.06
		212	Chapel &School		0.04	0.00	0.00	0.06	0.05	0.06
		213	Drying room		0.02	0.32	0.03	0.48	0.05	0.50
		214	Galley		0.02	0.32	0.03	0.48	0.05	0.50
		215	Laundry		0.10	1.60	0.02	0.26	0.05	0.27
		216	Sickbay		0.10	0.00	0.01	0.00	0.05	0.00
23	**Stores**	221	Beer & Canteen	S	0.00	0.08	0.00	0.04	0.05	0.04
		222	Cold & Cool roooms	S	0.00	0.26	0.00	0.25	0.05	0.26
		223	CO's and wardroom		0.25	1.25	0.21	1.05	0.05	1.10
		225	Medical		3.70	3.70	0.60	0.60	0.05	0.63
		226	Officer's baggage		2.50	2.50	0.03	0.03	0.05	0.03
		227	Provisions room		0.25	0.25	0.14	0.14	0.05	0.14
		228	Sports gear			0.00		0.00	0.05	0.00
		229	Victualling		0.10	1.60	0.03	0.50	0.05	0.52

			gear							
24	**Misc**	231	Lifesaving Equipment		0.00	0.00	0.01	0.18	0.05	0.18
		232	Personnel		0.00	0.00	0.14	2.29	0.05	2.40
		233	Refrigerated machinery	S	0.00	0.11	0.00	0.01	0.05	0.01
						339.48		**19.45**		**20.42**

				area	**vol**	**Total volume**	**weight**	**total weight**	**Margin**	**Weight estimate**
31	**AC, Ventilation & Chilled water**									
			AC, Vent	54.90	219.58	219.58	47.77	47.77	0.05	50.16
			Chilled water		50.00	50.00	5.00	5.00	0.05	5.25
32	**Sea and fresh water systems**									
		321	Reverse Osmosis		13.30	26.60	6.00	12.00	0.02	12.24
		322	Distribution		0.00	0.00	0.00	11.17	0.02	11.39
		323	Salt water generation		3.40	6.80	2.00	4.00	0.05	4.20
		324	Salt water distribution		0.00	0.00	0.01	47.46	0.05	49.83
33	**Fuel Systems**				0.00	0.00	0.26	19.76	0.05	20.75
34	**Auxiliary Systems**				0.00	0.00	0.00	5.00	0.02	5.10
35	**Hydraulic Systems**				0.00	0.00	0.00	16.3	0.02	16.30
36	**Compressed Air systems**				13.30	13.30	5.00	5.00	0.05	5.25
37	**Waste disposal system**				4.00	4.00	3.40	3.40	0.02	3.47
38	**Stabilisers**				0.00	0.00	0.00	0.00	0.02	0.00
39	**Aircraft systems**				4.00	4.00	2.00	2.00	0.02	2.04
						351.3		178.65		186.0

				area	**vol**	**Total Vol**	**Weight**	**Total weight**	**Margin**	**Weight estimate**
41	**Gas turbines**				12.00	24.00	19.00	38.00	0.02	38.76
42	**Generator**				12.00	24.00	18.00	36.00	0.02	36.72
43	**Steam turbines**					0.00		0.00	0.00	0.00
44	**Electric motors**						22.00	44.00	0.02	44.88
45	**Auxilliary machinery**					0.00		0.00	0.02	0.00
46	**Gearbox**					4.00		12.00	0.05	12.60
47	**Transmission**				10.00	20.00	4.00	8.00	0.05	8.40
			Brackets paring plates		0.00	0.00	18.00	18.00	0.05	18.90
			palm compartment		1.00	1.00		1.00	0.05	1.05
			shaft		0.40	1.60		4.47	0.05	4.70
			gland compartment		8.00	16.00	1.00	2.00	0.05	2.10
48	**Propulsors**				0.00	0.00	20.00	40.00	0.02	40.80
						90.60		203.47		208.91

						Total volume	Weight	Total weight	Margin	Weight estimate
				Area	**Vol**	**Total volume**	**Weight**	**Total weight**	**Margin**	**Weight estimate**
51	**Diesel gen**		gen mounting		23.20	46.40	16.00	47.50	0.02	48.45
			consoles etc		0.00	0.00	15.00	1.00	0.02	1.02
52	**Switchboards**		switchboards		0.00	0.00	10.00	10.00	0.05	10.50
			edcs		23.96	23.96	8.60	8.60	0.05	9.03
53	**General dist**				0.00	0.00	27.92	17.90	0.05	18.80
54	**lighting**				0.00	0.00	4.25	4.25	0.02	4.34
						70.36		89.25		92.14

6						Total volume	Weight	Total weight	Margin	Weight estimate
61	**Sonar**		gen		0.00	0.00	0.00	0.00	0.00	0.00
			Passive		0.00	0.00	0.11	0.11	0.05	0.12
62	**Radar**		switchboards		0.00	0.00	0.25	0.25	0.05	0.26
						0.00		0.36		0.38

				Area	**Vol**	**Total volume**	**Weight**	**Total weight**	**Margin**	**Weight estimate**
71	**Naval stores and spare gear**									
72	**Victualling and medical stores**									
		721	Dry provisions		0.00	0.00	0.12	0.12	0.05	0.13
		722	Frozen provisions		0.00	0.00	0.05	0.05	0.05	0.05
		723	fresh provisions		0.00	0.00	0.15	0.15	0.05	0.16
		724	beer		0.00	0.00	0.14	0.14	0.05	0.15
		725	clothing and mess gear		0.00	0.00	0.03	0.03	0.05	0.03
		726	NAAFI		0.00	0.00	0.12	0.12	0.05	0.13
73	**Weapons**				0.00	0.00	0.00	0.00	0.05	0.00
74	**Stowed Liquids**									
		741	Fuel		350.00	350.00	250.00	250.00	0.02	255.00
		742	Lub Oil		4.20	4.20	3.00	3.00	0.05	3.15
		743	AVCAT		2.80	2.80	2.00	2.00	0.05	2.10
		744	Water		4.71	4.71	4.71	4.71	0.05	4.94
75	**Operating liquids**				0.00	0.00	0.00	0.00	0.05	0.00
76	**Ammunitions**				0.00	0.00	0.00	0.00	0.05	0.00
77	**Aircraft**				0.00	0.00	0.00	0.00	0.05	0.00
78	**Vehicles**				19.38	19.38	8.00	8.00	0.02	8.16
79	**Cargo**		Vehicles		25.00	2725.00	325.00	325.00	0.01	328.25
			Tiedowns etc		2.00	2.00	3.00	3.00	0.05	3.15
						2872.4		**474.6**		**498.3**

Appendix E Risk Matrix

		Probability		
		Low	**Medium**	**High**
Consequences	**Low**	**Use of Spey gas turbines** There many in service Spey engines (including on very modern warships[xiv], requiring spares and upgrades, currently so the probability of availability is high.	**Crane** The crane type specified in this report is at prototype stages. The probability of mainstream use is currently not certain. If this type of crane cannot be used there are other cranes in use which are larger. This means that larger structures and costs may be incurred	
	Medium	**Compatibility** Due to the versatility, stability and large beam, probability of occurrence is low but consequences are high as the concept is redundant if it cannot link with other vessels. **PM Motor and generator** Availability of similar technology means that it will be probable that this equipment will be available. The use of a different motor and generator will result in a slightly less efficient hullform.	**Propulsor** Technology is already in use but not in this application. The use of a different propulsor would result in reduced efficiencies and a redesign of the drive system.	
	High		**Aluminum hulls** Medium probability of opposition to the idea of an aluminum hull. The ship is designed to be made from aluminum and cannot be manufactured from steel.	

Appendix F Scaling of Power and Resistance for HSSL Hullform

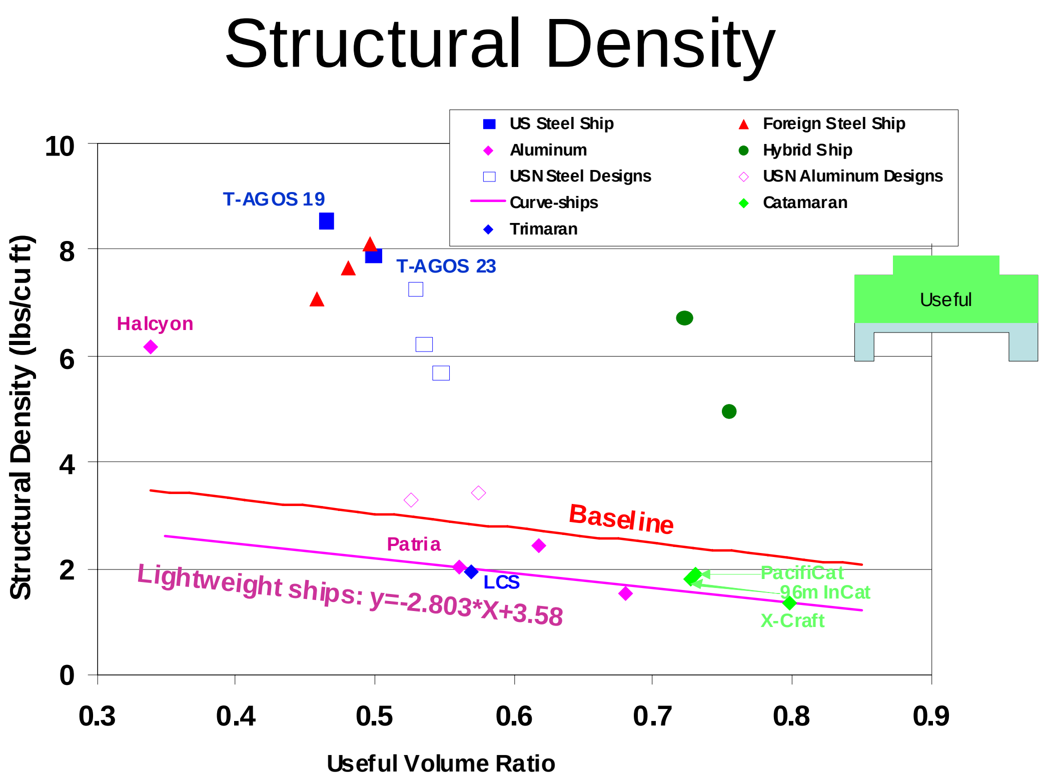
HSSL SWATH - Deep Displacement

Model			
Length (ft)	3.79	Ca	0.0002
Disp (lbs)	9.53	PC	0.7
Disp (cu ft)	0.15281017		
WS (sq ft)	3.64		

Ship	
Disp (LT)	1,463
Disp (cu ft)	51,130
Scale	69
Length (ft)	230
WS (sq ft)	17,543

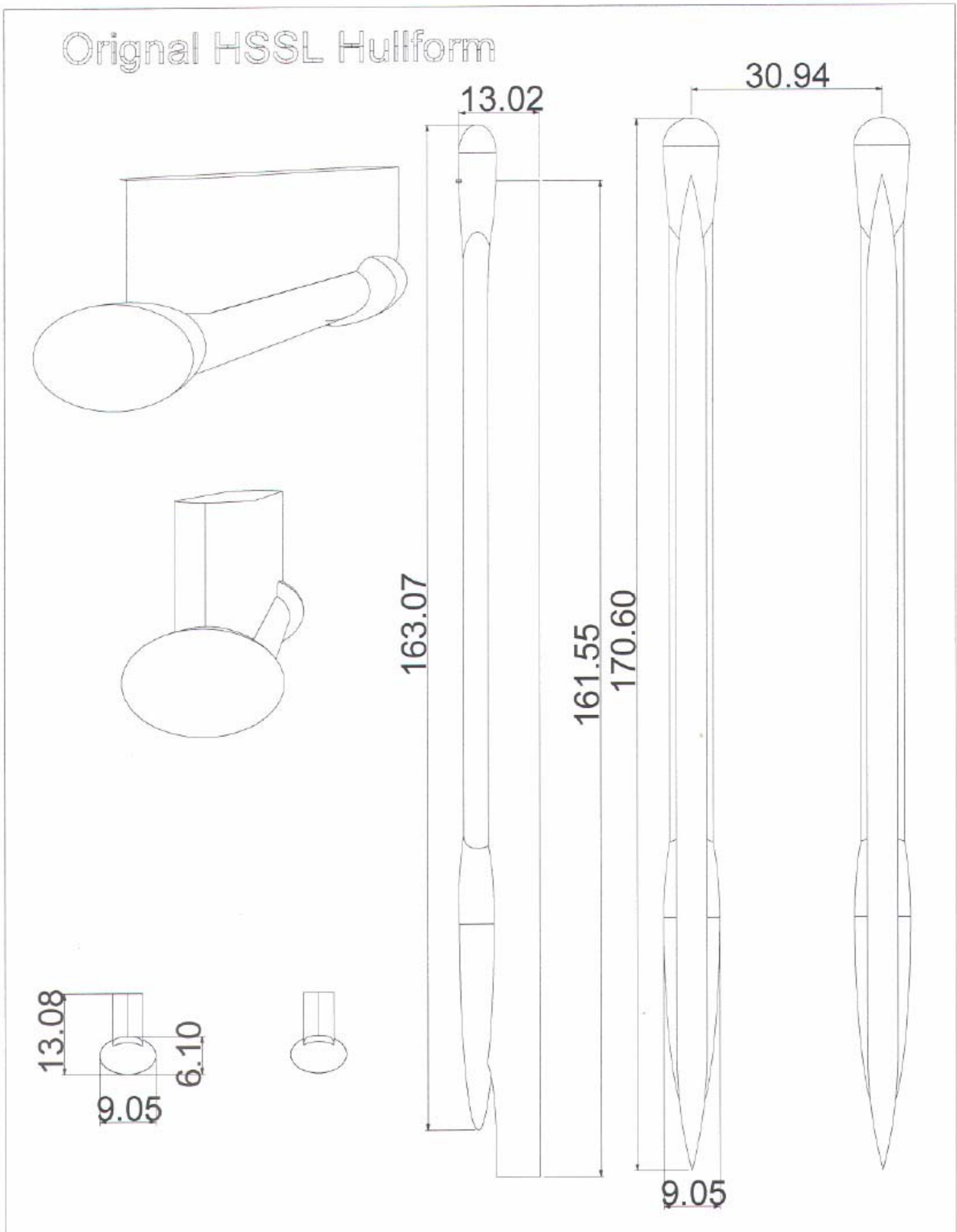
Model Speed (fps)	**Fn**	**Cr**	**Ship Speed (knots)**	**Re**	**Cf**	**Ca**	**Ct**	**EHP**	**SHP**
2.14	0.194	0.00107	10.56	3.21E+08	0.00177	0.0002	0.00304	547	782
2.85	0.258	0.00368	14.07	4.27E+08	0.00171	0.0002	0.00559	2,375	3,392
3.57	0.323	0.00385	17.62	5.35E+08	0.00166	0.0002	0.00571	4,768	6,811
4.28	0.387	0.002	21.13	6.41E+08	0.00162	0.0002	0.00382	5,498	7,854
4.99	0.452	0.00158	24.63	7.48E+08	0.00159	0.0002	0.00337	7,683	10,976
5.71	0.517	0.00225	28.19	8.55E+08	0.00156	0.0002	0.00401	13,711	19,587
6.42	0.581	0.00225	31.69	9.62E+08	0.00154	0.0002	0.00399	19,378	27,683
7.13	0.645	0.00183	35.20	1.07E+09	0.00152	0.0002	0.00355	23,617	33,738

Appendix G Ship Structural Density Diagram

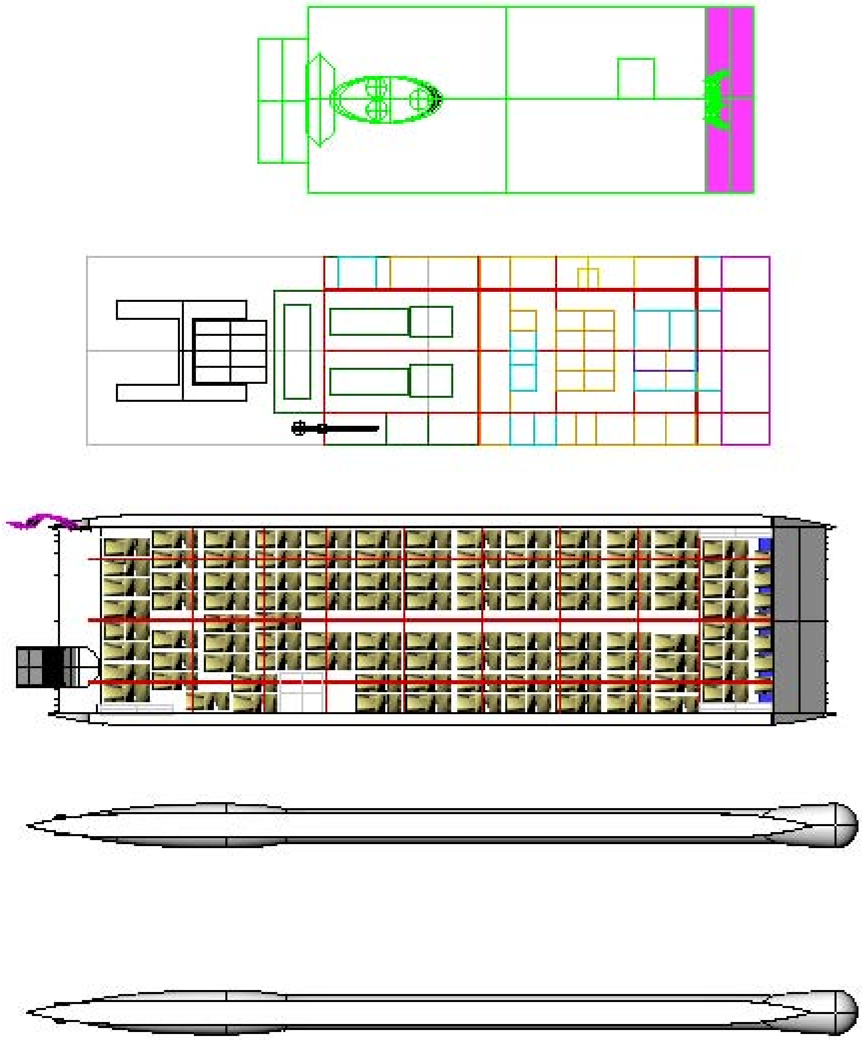


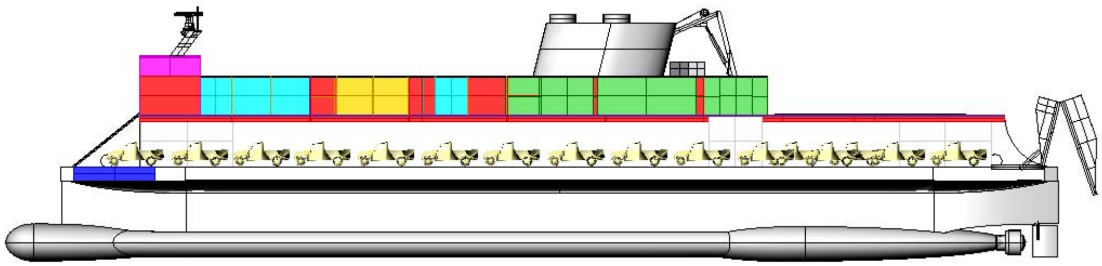
Appendix H SWATH Hullform

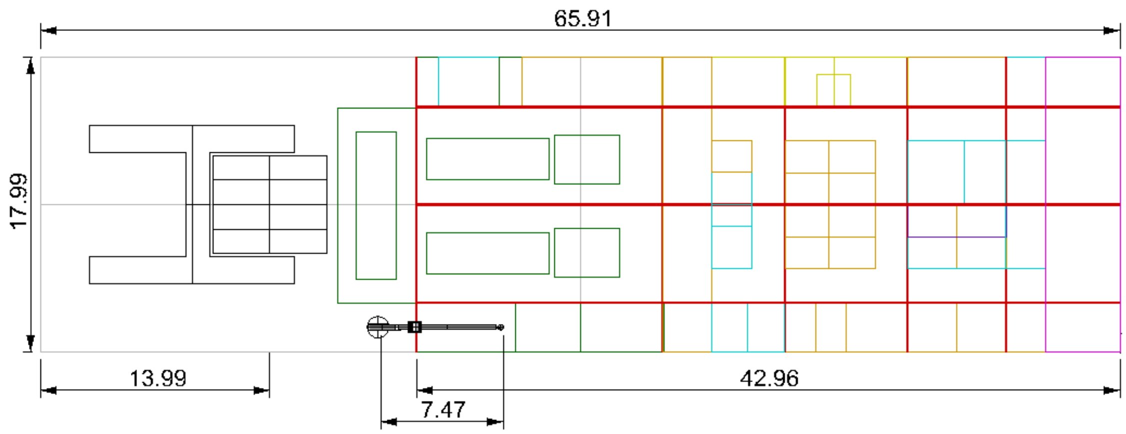
Units in Metres

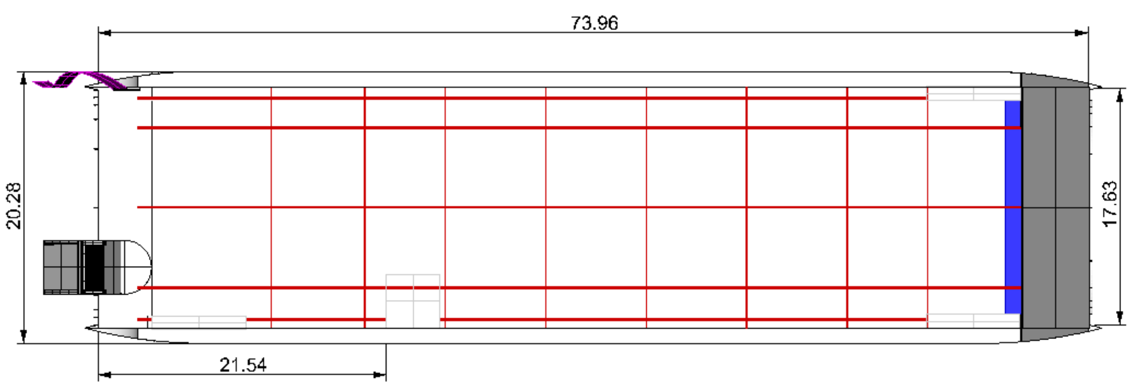


Appendix I General Arrangement Drawings

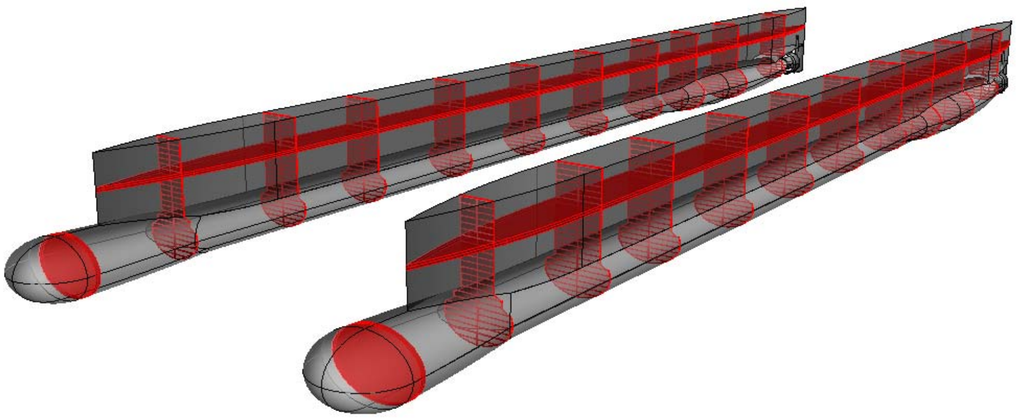


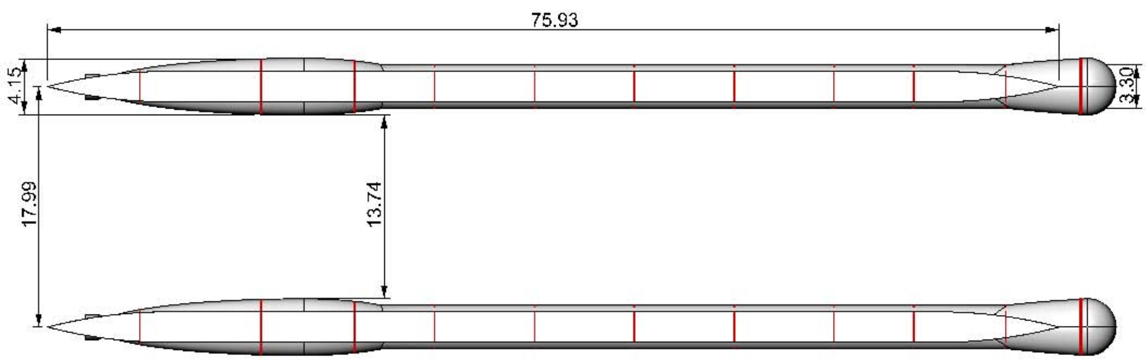



65.91
17.99
13.99
7.47
42.96


73.96
20.28
17.63
21.54

Appendix J ITALS Hullform





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